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FINAL REPORT
AUTOMATIC
DATA CORRELATION SYSTEM STUDY

Contract No.: NAS9-9842
Control No.: 2460

24 July 1970

VOLUME II: SYSTEM DESIGN

Submitted To:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

ABSTRACT

This document presents the results of a one year study (July 1, 1969 to June 30, 1970) to design an Automatic Data Correlation System for the Earth Resources Program at NASA Manned Spacecraft Center, Houston, Texas.

The study was devoted to the problems of correlating remotely sensed earth-surface data with other similar data and of correlating these data with the earth's surface.

A functional ground data processing system is described which is designed to handle all identified classes of remote sensor data on a large-volume, high-throughput basis. With that as a reference, a specific Pilot System configuration is recommended which, where possible, uses equipments already available at MSC.

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PREFACE

Considerable thought was given to the form and substance of this report with two primary objectives in mind: first, to allow the reader who is interested only in the results of the Study to obtain this information with a minimum of effort and, second, to organize the material in a fashion such that the reader desiring greater detail could readily follow the paths of logic taken by the Study team.

Accordingly, the report is divided into two volumes. Volume I contains a statement of the problem; the general nature of the proposed solution; a description of the recommended Pilot System; and a compilation of the major problem areas. This should provide the information required by the first reader without belaboring him with nonessential detail.

The organization of Volume II is based on the fundamental concept rather than on specific equipments or techniques. This treatment follows logically from the general approach wherein the system was, first, functionally designed in terms of the specified inputs and the desired outputs.

Then, as the study progressed from function design to implemention, the function concept was retained. As a concrete example, the raw data may exist on a number of film types & sizes and in various analog and digital tape formats. However, all operations performed on raw data prior to geometric or correlation processing are included in the function "Preprocessing".

Clearly, this is not ideal, since it results in a given equipment appearing in several parts of the report. Nevertheless, it is the consensus of the authors that this is less disturbing than the alternative, wherein the various functions (levels of processing) are repeated in different parts of the report. Hence, the serious reader is urged to adopt this functional picture (illustrated in Figure i) and to mentally relate any subsequent part of the report to it.

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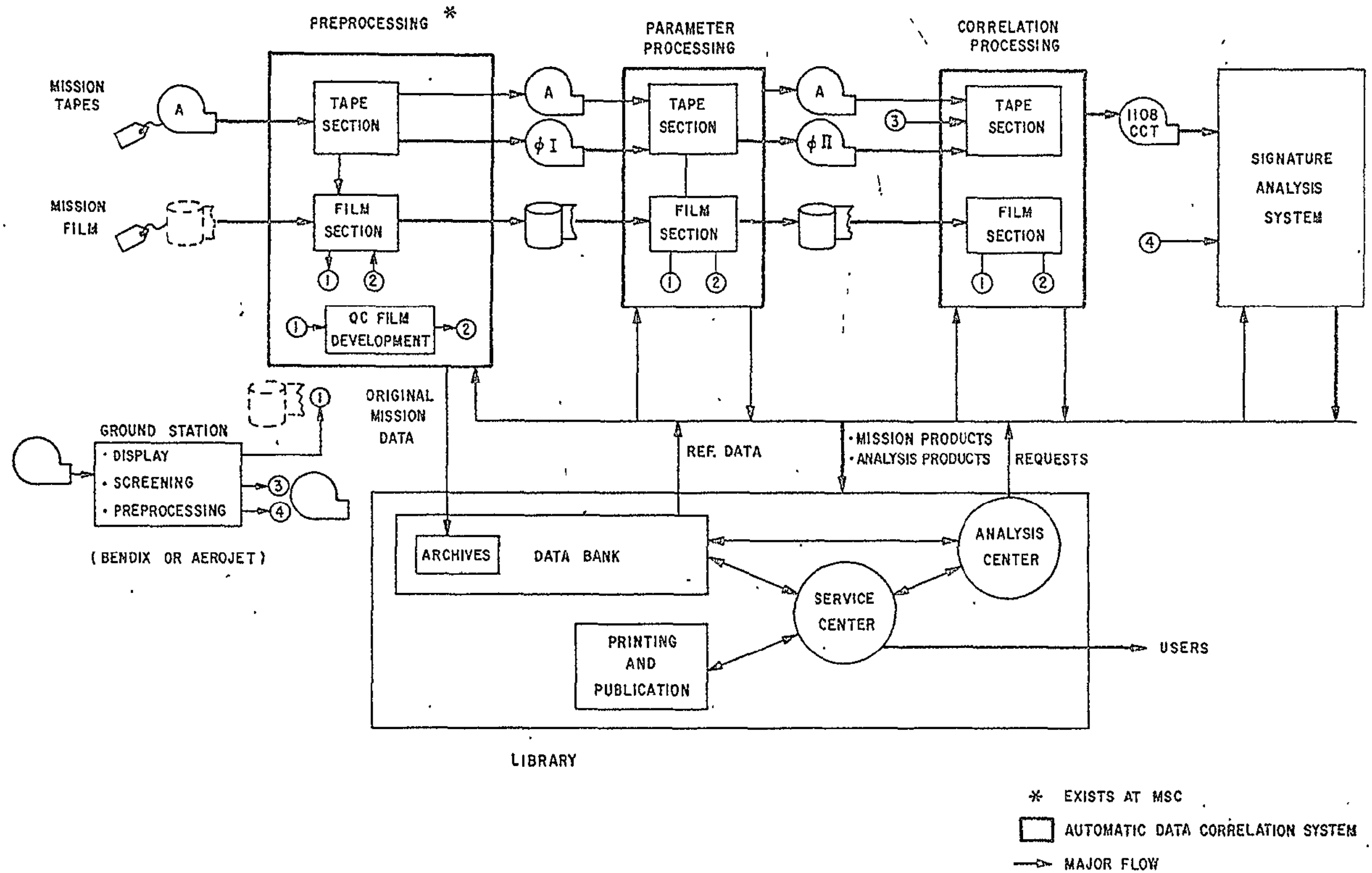
VOLUME II (cont.)



SYSTEM OVERVIEW

FIGURE i.

SECTION 4

SYSTEM REQUIREMENTS

FOREWORD

The overall problem introduced in Section 1 must be re-examined in more specific terms before it can be adequately solved. It is axiomatic that a system is fundamentally characterized by its inputs and outputs, and so a proper design must begin with a detailed review of those requirements. This section presents such a summary, indicates the various difficulties involved and establishes desired performance criteria.

SECTION 4 CONTENTS

4.1 INPUT DATA

One of the essential requirements on the Automatic Data Correlation System is flexibility. Hence, it must be established immediately that acceptable input data might be produced by sensors which do not currently exist or are not currently in use on the Houston aircraft program. Therefore, it is necessary to treat sensors in a more general way than merely examining a list of existing equipments. In particular, the concern is to identify those features which bear on the problem of data correlation.

Since the central issues are geometric and photometric correction, it is convenient to categorize inputs first on the basis of sensor collection geometry and then on the basis of data differences. Table 4-1 lists ten data types which appear relevant to the processing system design. Several classes contain sub-types which require some differences in specific processing steps but the more significant fact is their common membership in a characteristic class. Likewise, different sensor and auxiliary hardware will necessitate processing adjustments, but they will be relatively minor.

The following ten sub-paragraphs briefly outline the nature of the processing problem for each data class. Geometric corrections are discussed in detail in Appendix A, " Coordinate System Transforms".

4.1.1 Profile Sensor Data

Input Form .... • 1" Magnetic Tape.

• Direct, FM or PCM - coded.

Sensor Coverage ..... • Non-scanning aperture at fixed, or manually adjustable, look angle.

• Different sensors may have instantaneous field of views (IFOV) from approximately 1 milliradian to several degrees.

TABLE 4-1 INPUT DATA CATEGORIES

	DESCRIPTION	FILM	TAPE	AIRCRAFT	SPACECRAFT
1.	Profile Sensor Data				
	• Radiometer	---	PCM	X	
	• Thermometer	---	PCM	X	X
	• Spectrometer	---	PCM	X	X
	• Scatterometer	---	Direct, FM	X	
2.	Frame Photography				
	• Mapping	9 1/2"	---	X	
	• Multi-Spectral	70mm-5"	---	X	X
	• Boresight	70mm	---	X	
3.	Panoramic Photography	70mm-5"	---	X	
4.	SLAR Imagery	5"		X	
5.	Point Scanner Imagery				
	• Infrared	70mm-5"	FM	X	
	• Multi-Spectral	---	PCM	X	X
	• Microwave	---	PCM	X	
6.	Push-Broom Line Imagery				
	• Solid State Array	---	PCM	X	X
7.	Television Imagery				
	• RBV	---	Direct Video		X
8.	NAV Data	---	PCM	X	X
9.	Housekeeping Data	---	FM, PCM	X	X
10.	Ground Truth	X	X	-	-

Sensor Coverage ....
- Some data (e.g., radiometer outputs) may represent time-integrated measurements.
- Spectral range can vary from UV through IR or into microwave regions.

Special Problems...
- Scatterometer and passive microwave radiometer processing require separate data reduction rountines.
- Input formats can vary considerably.

Class Problems

- Locate the ground intercept "spot", given readings of vehicle heading (θ), altitude (H), latitude ($\emptyset$), longitude (λ), pitch (ρ), roll (ω), yaw (η) and sensor offset (δ), IFOV (β) and integration time (T_I).

- Maintain signal fidelity; adjust data to calibration standards.

4.1.2 Frame Photography

Input Form ....
- B & W, Color or Color-IR Film
- 70 mm, 5", 9 1/2"
- Fixed look angle; boresight cameras adjust with profile sensors
- IFOV from a few degrees (boresight) to about 21 - 31° for multi-spectral cameras to, typically, 74° for mapping cameras.
- Spectral range determined by camera filters and film emulsion response.

Special Problems...
- Auxiliary data code blocks can be positioned differently on different camera outputs and can be left-right reversed.

Special Problems.... . A recorder malfunction could cause blocks to be missing. This should not be allowed to prohibit the use of the corresponding photography.

Class Problems

- Locate the ground point corresponding to any set of image coordinates, given vehicle data and camera format, focal length (f), cycle rate (T_{frame}) and start/stop times.

- Rectify the imagery, if warranted by the application.

- Optimize the imagery by performing a Quality Controlled (QC) film processing, given film type, batch characteristics and the exposure parameters...filter, lens, window, f/stop, shutter speed, atmospheric conditions.

4.1.3 Panoramic Photography

Input Form .... B & W, Color or Color-IR Film

. 70 mm, 5"

Sensor Coverage.... . A slit aperture, parallel to the longitudinal axis of the aircraft, is rotated so as to sweep out the view in the lateral direction. The net result is a longitudinal coverage on the order of 20 - 74° and a lateral coverage that can range to 180°.

Special Problems... . Same as for Class 2

Class Problems

- Locate the ground point corresponding to any set of image coordinates, given vehicle and camera data as indicated plus ground speed and sweep rate. Note that vehicle motion produces an "S - distortion" within each frame.

Rectify the imagery, if warranted.

Perform QC film processing.

4.1.4 SLAR Imagery

Input Form............
- B & W film, via CRT recorder
- 5" (typical)

Sensor Coverage.......
(Typical)
- 2° x 56° beam, one side of the aircraft.
- Synthetic aperture -- either unfocused or focused.
- 16.5 GHz
- Max range ≈ 10nm
- Depression angle might be adjusted in flight.

Special Problems......
- Ground resolution on the order of 100 x 100 feet.
- CRT recorder may or may not have sweep compensation for slant range/ground distance correction or aircraft roll. It will, in general, not compensate for pitch and yaw, but it could be made to.
- Code block problems -- same as Class 2.

Class Problems

- Locate the ground point corresponding to any set of image coordinates given vehicle data and sweep sync times. Note that for active sweep intervals on the order of 122 μ sec (10nm range), any one data line corresponds to a fixed set of vehicle parameters; however, the continuous strip imagery has "rubber sheet" distortion due to vehicle perturbations over longer time intervals.

Rectify the imagery, if warranted.

Perform QC film processing.

4.1.5 Line Scanner Imagery

Input Form ....

- 1" Magnetic Tape, FM or PCM; and/or
- B & W film, 70mm or 5", via CRT recorder

Sensor Coverage ....

- Aperture scans in the lateral direction
- IFOV on the order of 1-3 milliradians for IR and Multi-spectral types; few degrees for microwave imager.
- Total scan of about ± 40° to 60°
- Scan rate may or may not be adjusted for V/H, and sync may or may not be adjusted for roll.
- Spectral range UV-IR, microwave

Special Problems ...

- CRT Recorder may or may not have sweep compensation for tangent correction (rectilinearization) or vehicle roll. It will generally not include pitch and yaw compensation.
- Code block problems .. same as Class 2.

Class Problems

- Locate the ground point corresponding to any set of image coordinates given vehicle data, scan sync, angular scan range and scan rate. For rates on the order of 200 scans/second vehicle motion will normally contribute negligible distortions line-to-line but the overall strip image will have "rubber sheet" distortion as in Class 4 imagery. However, lower scan rates will introduce "S - distortions" within scan lines as in Class 3, and high speed attitude variations also can produce significant distortions within a line.

- Rectify the imagery, if warranted.

- Perform QC film processing.

4.1.6 Push-Broom Line Imagery

Note: This is a hypothetical category in that no such sensor currently exists. Ideally, it would consist of a linear array of solid-state detectors viewing a straight line which runs in the lateral direction. However, in practice, the configuration will probably consist of linear sub-arrays which are approximately in line. Another sensor which belongs to this category is the planned SIS system which also uses line exposures.

Input Form..........	• 1" Magnetic Tape
	• Detectors will probably be read in parallel sub-groups
Sensor Coverage..... (Typical)	• 1000 - 10,000 elements
	• S/C swath -- 100nm
	• Spectral range--0.3 - 1.1 μ, probably in 3-4 bands; more advanced systems may cover the range 0.3 - 10 μ in as many as 10-20 bands.
Special Problems....	• Recorded data must be adjusted in sequence if it is to be ordered according to ground elements.
	• Detector non-uniformity may necessitate device-signature compensation.
	• Code block problems --same as Class 2.

Class Problems

- Locate the ground point corresponding to each detector reading, given vehicle and scan data. For "exposures" (i.e., the detector integration interval between successive readouts) on the order of 10 milliseconds, line-line distortions will be negligible for normal attitude rates.

"Rubber - Sheet" distortion will again be present.

- Rectify the imagery, if warranted.

- Maintain signal fidelity and perform QC film processing.

4.1.7 Television Imagery

Input Form..........	• Magnetic video tape ($\approx$ 4 MHz BW), or
	• 70 mm or 9 1/2" B&W film
Sensor Coverage.....	• 100 x 100 nm area per frame (simultaneous exposure of 3 cameras)
	• 4000 - 6000 scan lines; might eventually go to 10,000 - 12,000 lines.
	• Spectral range -- .475 - .830μ in 3 bands (per ERTS A spec).
Special Problems....	• Assuming matched lenses and perfectly known optical boresighting, the 3 cameras will still have differential distortions due to sweep non-linearities and raster size, skew and offset variations. These can be corrected by using an etched faceplate on each of the cameras, locating the corresponding video elements and adjusting the imagery according to error measurements on the grid data.
	• Camera response characteristics must be calibrated out.
	• Annotation -- similar to code block problems except ground equipment may also be at fault.

Class Problems

- Locate the ground point corresponding to any set of image coordinates or any video element (depending on the form of the input to the Correlation System). Once the camera distortions are removed, the remaining problem is identical to that of frame photography from a spacecraft.

- Rectify the imagery, if warranted.

- Maintain signal quality and perform QC film processing.

4.1.8 NAV Data

Input Form..........	. 1" Magnetic Tape
	. PCM
Data Content.........	. Time ...tenths of a second
(ASQ-90 format)	. Latitude & Longitude ...tenths of a minute.
	. Heading....tenths of a degree
	. Drift, Roll, Pitch...tenths of a degree
	. Barometric Altitude...hundreds of feet
	. Radar Altitude...tens of feet
	. Ground Speed...feet per second
	. Date...day/month/year
	. Mission & Site numbers
	. Flight Line and Run numbers
	. System status

Special Problems....

- Position data is subject to instrument drift errors, so check point procedures must be used for update and correction purposes.
- Portions of the system may fail. If so, appropriate measures must be taken in the ground system in order to make the prime sensor data usable.
- Spacecraft NAV data must be augmented by orbit ephemeris data. Precision systems whose payloads include star field cameras will also necessitate the use of star field readings and catalog information.

Class Problems

- Extract, test and correct the vehicle NAV data

- Where the application demands higher positional accuracy than available from the Automatic NAV, satisfy the requirement by using prime sensor imagery (e.g., via resectioning calculations or image correlation techniques).

4.1.9 Housekeeping Data

Input Form........

- 1" Magnetic Tape
- FM, PCM, Direct

Data Content.......

- Time
- Sensor control settings (mode, look angle, gain, level, etc.)
- Sensor reference signals

Data Content....... • Camera Sync

• Operator entries (Voice)

Special Problems... • Variable formats

Class Problems

- Decommutate, sort and reformat the data according to their roles in the sensor data processing tasks.

4.1.10 Ground Truth

Note: In addition to on-file reference material such as site maps, orthophotomaps, coordinate standards, regional history, etc. there are two types of "ground truth" that can be considered mission inputs:

a) Derived signatures of known ground elements, based on the mission multi-spectral photography.

b) Field measurements and status reviews (e.g., crop stage and health) that were coordinated with vehicle overflights. These may include measurements of the local atmosphere, soil and water states as well as spectral radiation levels.

Input Form...... • Film, Magnetic Tape, handwritten logs.

Coverage........ • Reference plots of arbitrary size

• Any spectral region

• Measurements of any valid parameter

Special Problems... • Special calculations & formatting for data reduction to system-compatible forms.

Class Problems

- Locate, scan out and store the scan values for those portions of the multi-spectral imagery that correspond to ground control plots.

- Coordinate and reformat all newly available ground truth so as to be compatible with signature analysis requirements.

4.2 SYSTEM OUTPUTS

In order to discuss system outputs, it is necessary first to view the operational context within which the Automatic Data Correlation System functions; i.e., the system boundary and interfaces first must be defined. A later study will be needed to analyze these interfaces in depth and to clearly delineate the line where mating systems join; for present pruposes, it is assumed that the arrangement will be as shown in Figure 4-1.

The outputs of primary concern are the heavy lines labeled "Cell Data" and "Master Outputs". All other interface flows (inputs and outputs) must be accommodated also, and they will be treated in other sections of this report.

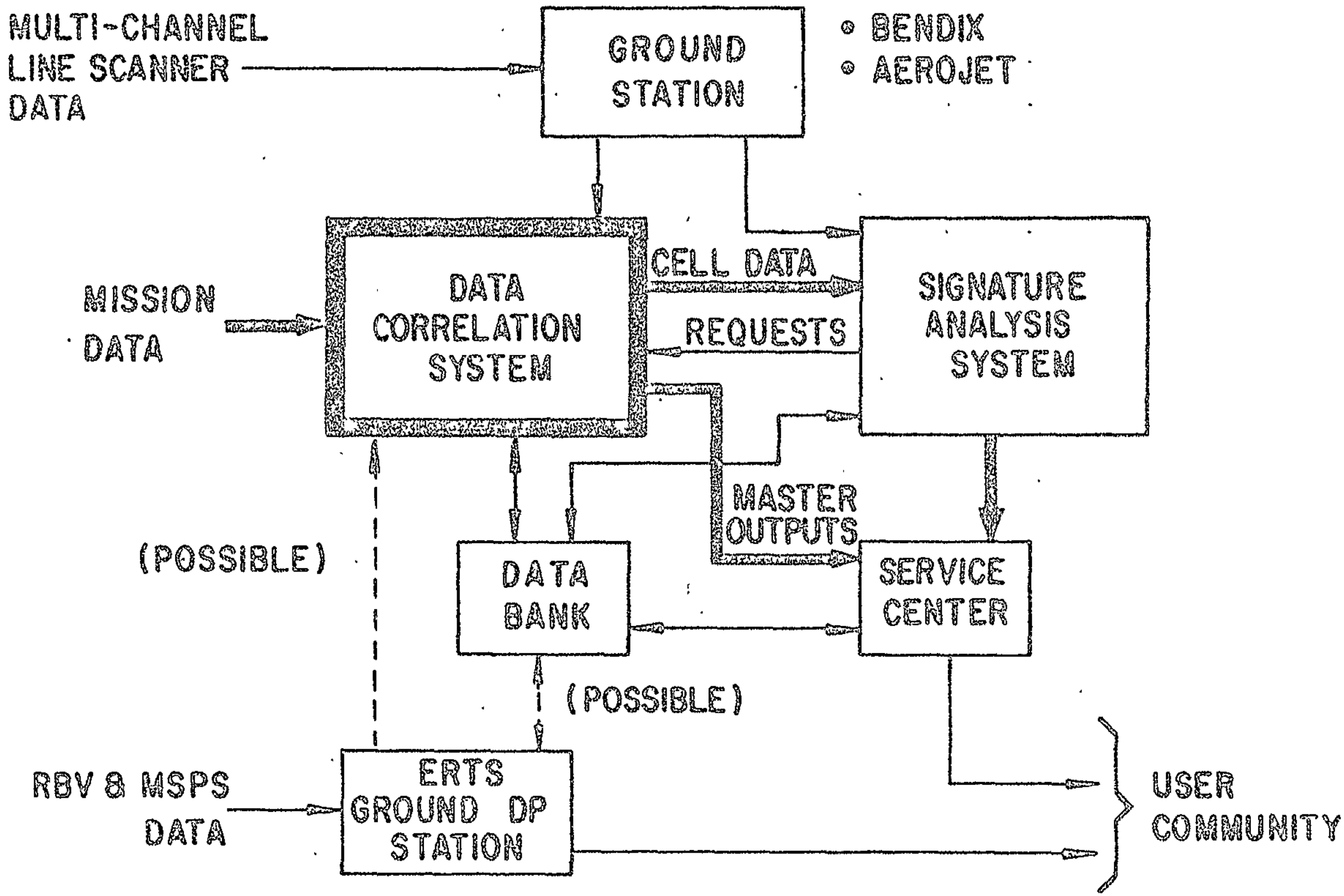
4.2.1 Cell Data

Data to the Signature Analysis System must be properly formatted and delivered on 1108 Computer-Compatible Tape (CCT). This consists of element values derived from:

- Scanning color or color-IR photographs or sets of multi-spectral B&W photographs;

- Extracting data segments from analog or digital magnetic tapes.

In addition, "elements" refers to image or ground cells whose dimensions may vary with different items of interest so there must be provision for combining several film - scanned "spots" or analog or digital sensor readings into single cell values. Further, the system should be adaptable so that combinations can be formed on a weighted basis which reflects the relative ground cell/sensor intercept geometry (see Section 9.5).



SYSTEM INTERFACES

FIGURE 4-1.

4.2.2 Master Outputs

Signature identifications must eventually be converted to some desirable output product(s) and delivered to the User Community. It is not at all clear yet where this ought to be done or what transforms are to be effected. In fact, the Data Correlation System, the Signature Analysis System and the Library Center may all contribute to these activities. Regardless of the arrangement, it appears that the overall system must be able to produce master (i.e., original) copies of material that can fall into any of three classes:
DATA, INFORMATION, or RECOMMENDATIONS.

To date, the following types of output product have been identified:

DATA

1) Copies of original mission films and tapes — Required

   - Complete set or only within an area of interest.

2) Modified imagery — Required

   - Gridded and/or annotated
   - Enhanced
   - Rectified
   - Orthophotos (possibly multi-spectral or color)
   - False color composites
   - Color separations

3) Modified tape data — Required

   - Gridded and/or annotated
   - Normalized or enhanced
   - Rectified ordering of data elements
   - Ground or image cell values (component or net)

4) Converted forms — Required

   - Tapes derived from film scanning equipment
   - Images reconstituted from tape data (e.g., IR line scanner tapes)

INFORMATION

1)	Plots of profile sensor ground intercept lines on mapping camera photography.	Required
2)	Statistical plots	
	- Scatterometer data analysis	Required
	- Signature data analysis	Desirable
	- Trends	Desirable
3)	Thematic maps (B&W or Color)	Desirable
	- Factor analysis imagery	
	- Crop distributions/status	
	- etc. (per discipline)	
4)	Summary estimates	Desirable
	- Area	
	- Yield	
	- Factor analysis statistics	
	- etc. (per discipline)	
5)	Hazard evaluation	Goal (Long Range)
	- Vegetation blight	
	- Air and water pollution levels	
	- Tsunami detection	
	- etc.	
6)	Equipment performance summaries	Required
	- Prime sensors	
	- NAV	
	- Other	

RECOMMENDATIONS

1)	Emergency measures warranted	Goal
2)	On-site observations needed	Goal
3)	Sensor or auxiliary equipment maintenance required	Goal

Table 4-2 summarizes the forms in which these outputs may be produced, depending on user requests.

4.3 PERFORMANCE

There are three primary indices for gauging the performance of a system such as the ADCS:

- Metric precision
- Data quality
- Throughput properties

At present, no rigid specifications can be defined for any of these areas; rather, the eventual system will evolve out of a compromise among cost, availability, performance and needs. However, one can attach a range of values that reflect reasonable goals. These quantities are extremely useful in sizing the problems ahead. They are surveyed in the next three subparagraphs.

4.3.1 Metric Precision

It is customary to distinguish between "absolute" and "relative" accuracies, where the first refers to the ability to position a data element on some reference grid and the second describes a bound on the distortion displacements within the data set. Thus, for example, if a camera-carrying satellite rolled so that the picture center were displaced several nautical miles, then all element coordinates would accrue an absolute error of that magnitude. However, the total ground distance covered in either dimension might change by only a few hundred feet, so the relative errors introduced within the image would be on a different scale altogether.

TABLE 4-2 OUTPUT FORMS

FILM	B & W	COLOR
• Duplicate negative	X	
• Duplicate positive transparency	X	X
• Paper prints	X	X
• Glass plates	X	

MAGNETIC TAPE

- Analog
- Digital (computer-compatible)

"STANDARD" PRODUCTS

- X/Y Plotter charts
- Oscillogram recordings
- Line Printer listings
- Microfilm plots and tabulations
- On-Line displays

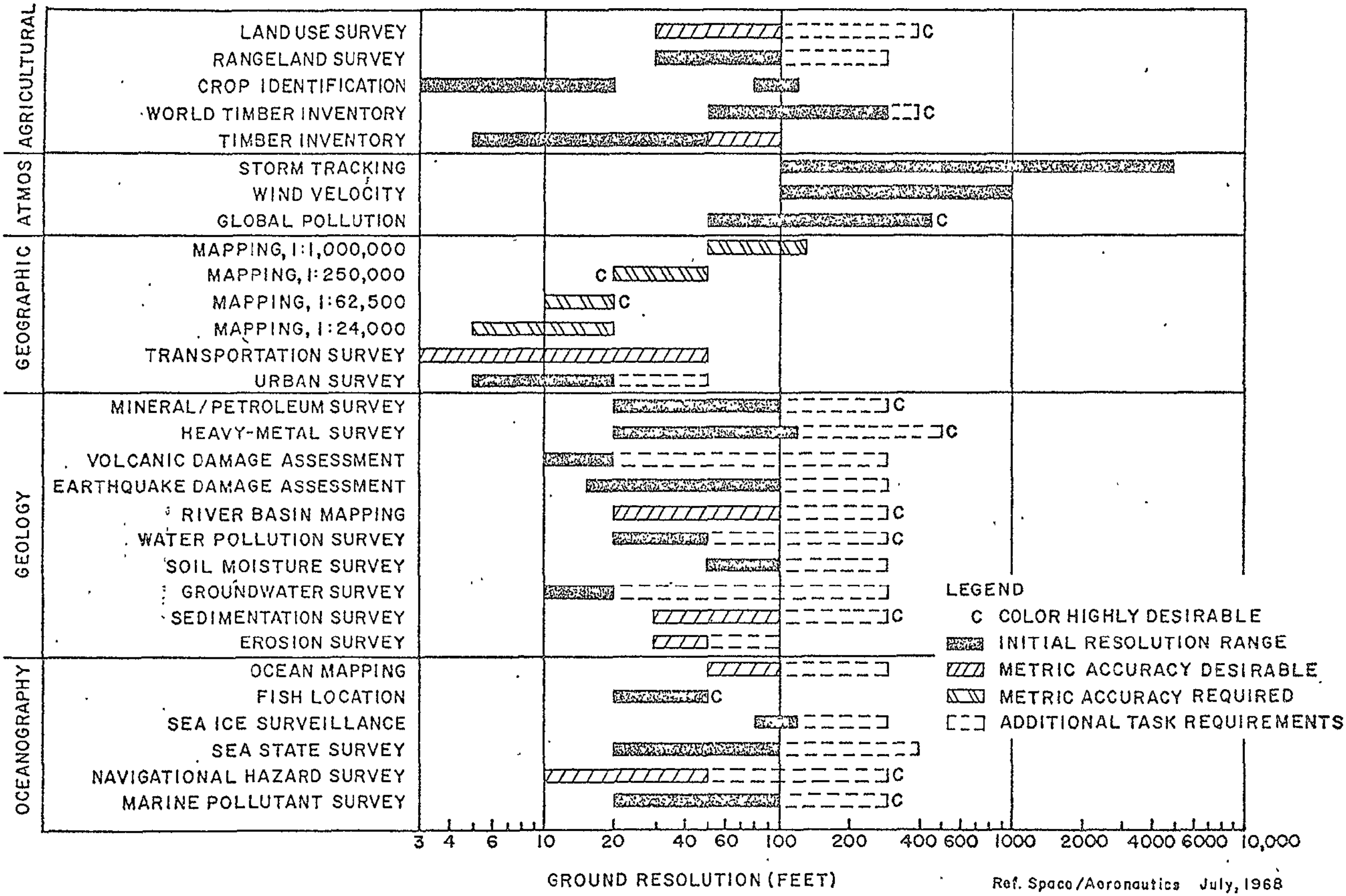
Both types of error are correctable, provided all contributing sources are precisely known. Generally, it is more important to control local distortion than absolute placement since the latter can be adjusted, or merely recognized, manually. Hence, after correction, registration between adjacent data lines from a scanning system would be required to be held to a fraction of a resolution element while the absolute placement of any datum might be specified in tens of resolution elements.

A case in point is the ERTS-A SPECIFICATION for precision imaging data (Section 7.14.3.2.7 Op. Cit.). After correction, selected sets of RBV or MSS images must be capable of being registered to within one picture element (as a goal), whereas the ground location of any part of the scene must be correct to 1700 feet. For a ground resolution on the order of 100-200 feet, the requirement on absolute accuracy is therefore 8-17 elements.

Restated more meaningfully, the point is that data-data registration must be established to within one (image or ground) correlation cell but that, ordinarily, it is less important to know the exact ground coordinates. But the ground is the necessary connecting reference between arbitrary data sets. Hence, for some applications, data collected simultaneously from a single vehicle (not necessarily from a single sensor) may be ground-referenced fairly coarsely but, in all other cases, the requirements on "absolute" accuracy and "relative" accuracy are identical, viz., a fraction of one ground correlation cell, say 1/2.

If a multi-vehicle experiment or a desire for a precise time-history analysis is hypothesized, it is immediately apparent that "other cases" can occur. Consequently, a technique is needed whereby some data (from aircraft) can be located to accuracies on the order of perhaps 5-10 feet, but not necessarily all data or even most data. Clearly, there will be a different solution called for when delivering accuracies at the 1nm level. Figure 4-2 summarizes the resolution/registration needs of representative Earth Resources disciplines.*

*....... Thomas, Space/Aeronautics, July 1968



GEOMETRIC ACCURACY GOALS

FIGURE 4-2.

4.3.1.1 Error Magnitudes

Photogrammetric errors associated with airborne and spaceborne sensor systems are amply documented and analyzed in the literature and will be only touched on here. The intent at the moment is merely to convey a quantitative idea as to the equivalent ground displacements that can be expected.

For some time yet, high accuracy applications will be serviced exclusively by aircraft collections. Positional errors in the navigation system might be held to values on the order of 50 feet by recalibrating over known checkpoints in the site area, but then further displacements are introduced by pitch, roll and yaw perturbations of the vehicle during the collection runs. The exact effects on data element locations are a function of the sensor geometry and the particular combination of offset angles (see Section 4.1 and Appendix A). For present purposes, only a gross sizing is of interest so it is convenient to consider the effect of a net angular offset on an initially vertical axis. This corresponds to the absolute error introduced at the center element of all vertically-oriented sensors, and is the least error produced.

The relationships for three representative altitudes are shown in Figure 4-3. Note that even at altitudes as low as 10,000 feet, a platform uncertainty of only 1 degree produces a minimum data ambiguity of 175 feet. Similarly, Figure 4-4 shows the corresponding plots for vehicles at 100 nm and 500 nm.

In all cases, altitude errors affect image scale, and the displacement error increases away from the nadir. In the ERTS system, for example, the maximum off-nadir distance is 10% of the altitude error. These errors arise from two sources: changes in vehicle elevation with respect to some reference, and variations in the relief of the overflown terrain. The latter is, of course, completely uncontrollable and can introduce differential displacements within the image.

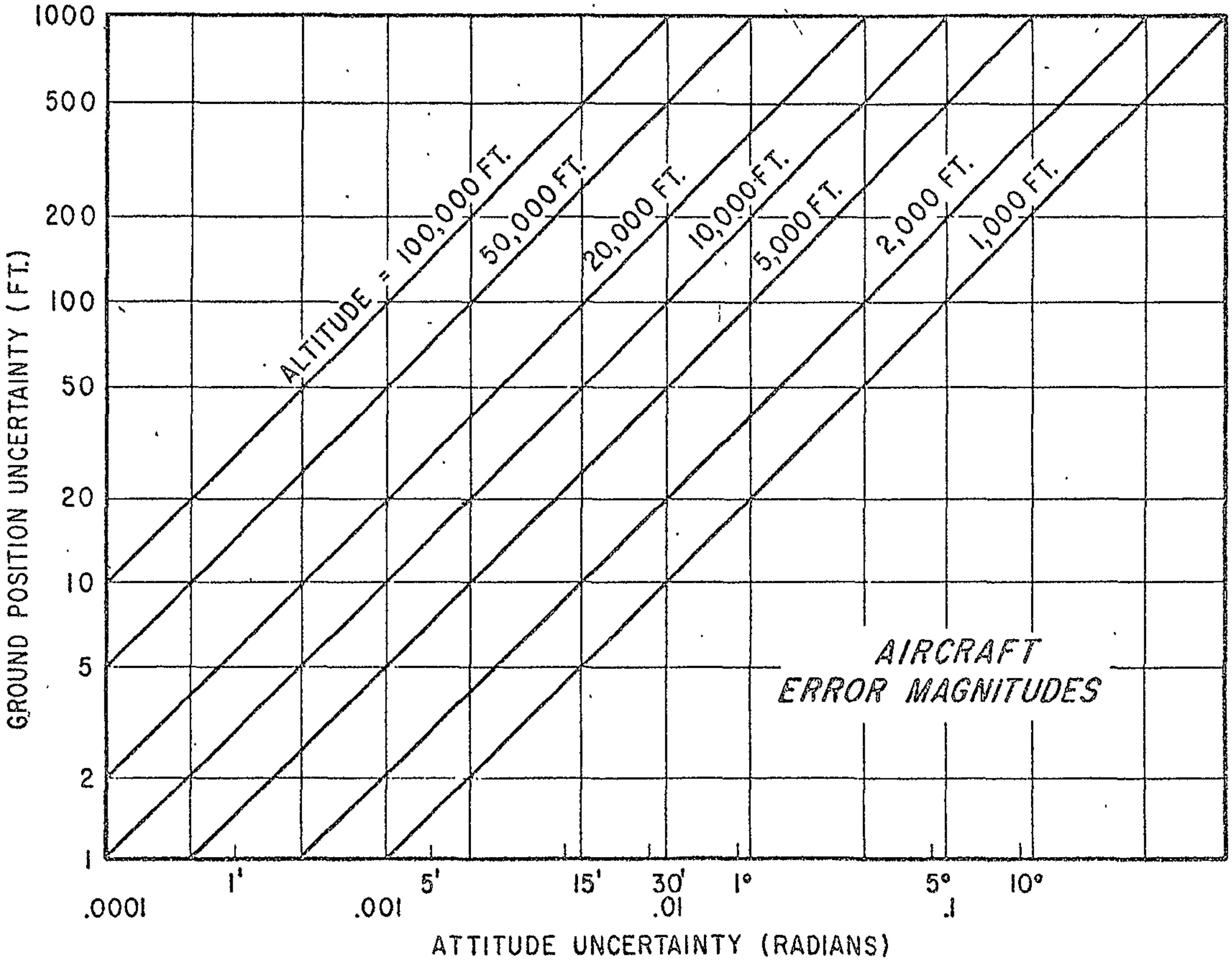
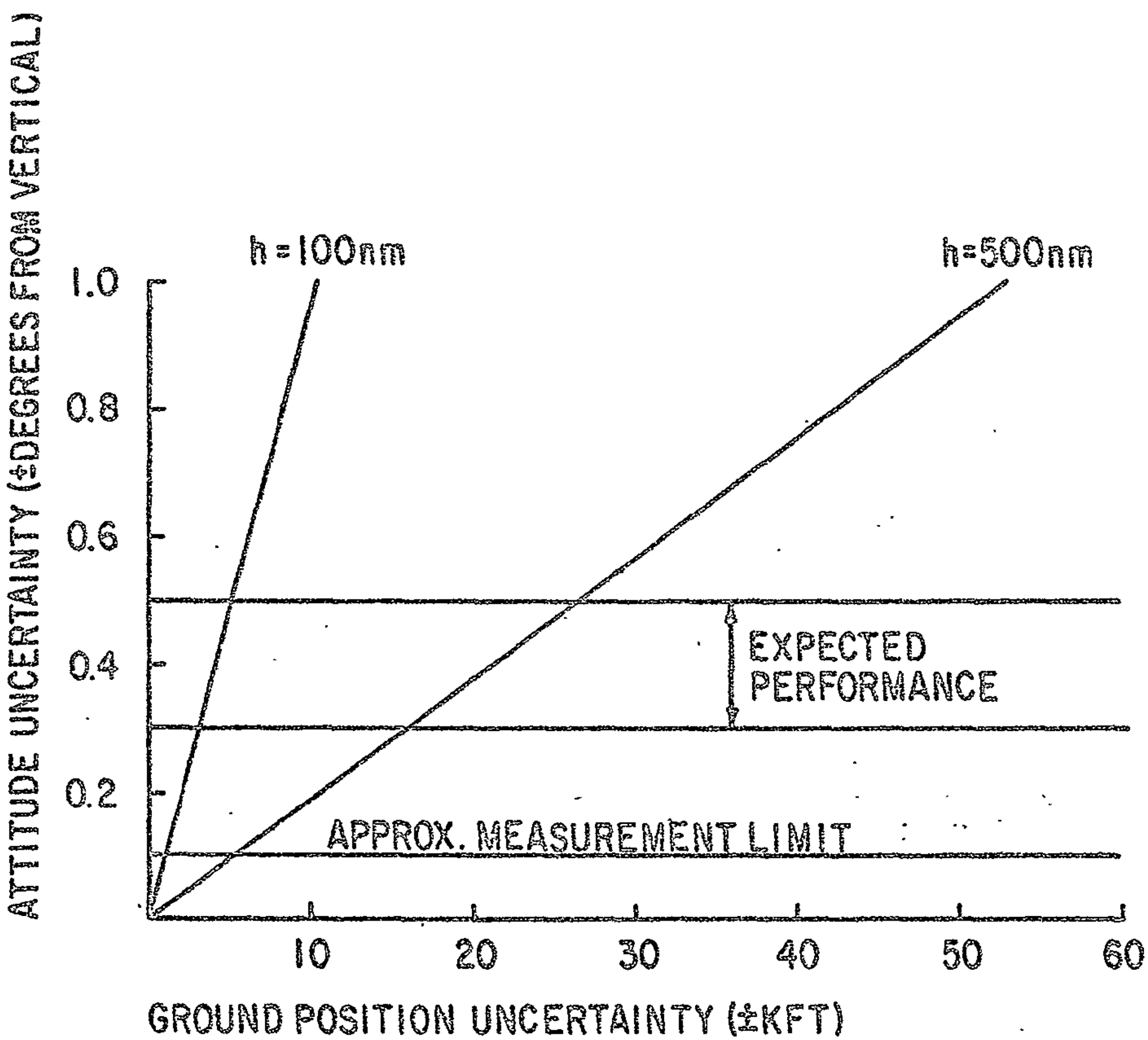


FIGURE 4-3. AIRCRAFT ERROR MAGNITUDES



SPACECRAFT ERROR MAGNITUDES

FIGURE 4-4.

4.3.2 Data Quality

The one general rule regarding data quality is that the ground processing system must not significantly degrade sensor collections in any way. For present purposes, this is an adequate guideline. Eventually, it should be converted to detailed equipment specifications but that is beyond the scope of the present study.

No insurmountable difficulties with regard to quality are anticipated. However, particular attention should be given to photographic processing because the corresponding film products are inherently analog in nature and will be put to use in all the high-accuracy applications. Potential problems can be avoided if care is taken at the outset to establish QC laboratory standards. This topic is treated in greater depth in Section 7. In addition, both Eastman Kodak and Ansco publish laboratory manuals dealing extensively with QC procedures.

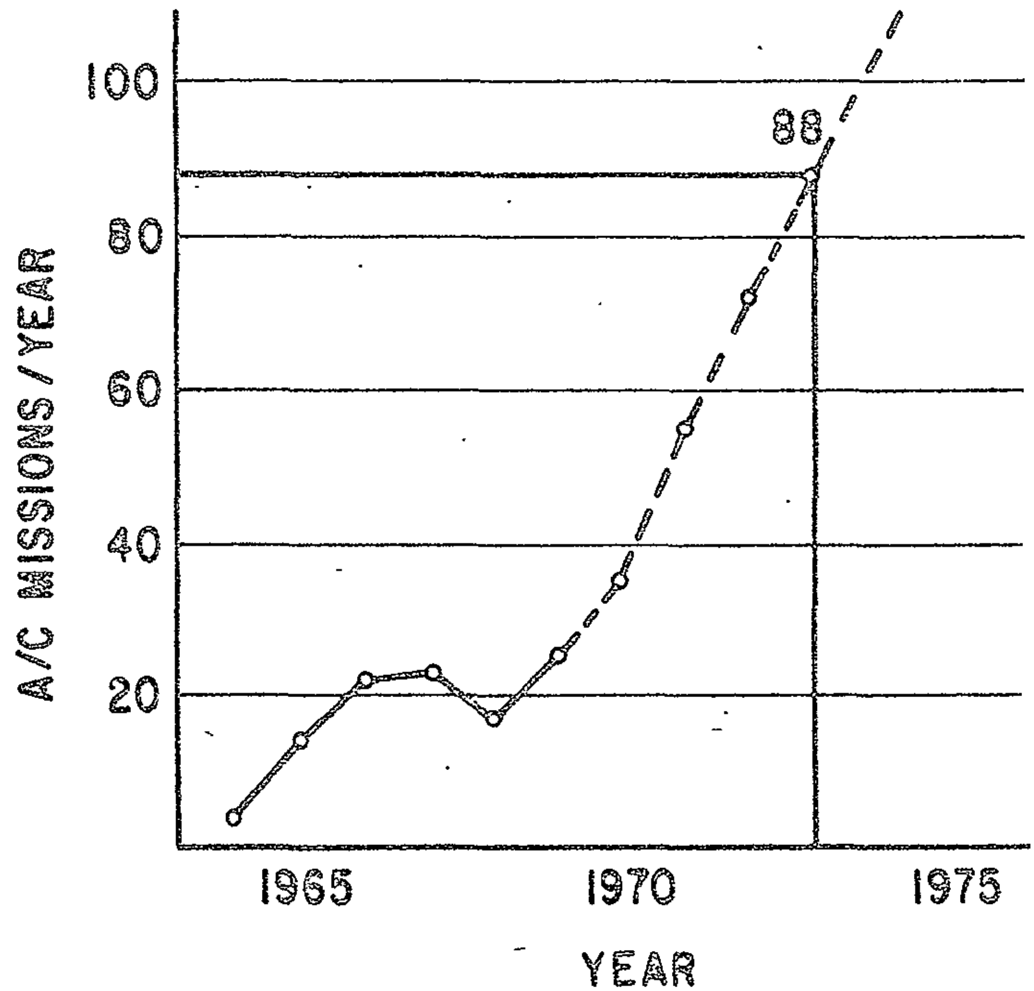
It is understood that the Apollo Applications Program at NASA, MSC, is currently modifying the Photo Technology Laboratory there by instituting extensive and well planned QC methods. If the same laboratory is made available to the Earth Resources Program, the photo quality problem will be largely solved. But even if throughput loading prohibits shared usage, the knowledge will be available in-house at MSC and so the problem should be well contained.

4.3.3 Throughput Properties

The initial version of the ADCS will be a pilot model which will be used primarily as a learning tool. Therefore, greater emphasis should be placed on functional capability, low cost and quick availability than on high throughput rates. For this first system, in fact, many film handling operations will have to be conducted on a frame basis rather than via roll film. The alternative is to modify 8 types of equipments, some of which could require extensive redesign, before having any experimental capability at all. It seems unwarranted to launch into such an undertaking merely to improve the throughput rate of the first system. Furthermore, desirable rates for different equipments are unknown and will remain so until flow interactions are well understood. That will come about only through operational experience with the primitive system. Then, at a later time, equipment development programs can be specified and phased properly.

Hence, for the pilot, throughput should be considered merely one of the factors to be "optimized" in the cost/availability/performance trade-off.

In the longer view, the production processing system will have to accommodate at least those inputs derived from the Houston aircraft program. Figure 4-5 shows how that activity has grown historically and projects what could happen over the next few years. 1973 is a reasonable target date for a fully operational (i.e., all services) ground system at MSC. At that time, the program could be flying some 88 missions per year. At an equivalent collection "take" of on the order of 5500 feet of film per mission, the ADCS would have to "accommodate" about 40,000 feet of film per month. To "accommodate" the film means to accept it, screen it, process it, convert it to usable forms and distribute it to users who need different products and at different response times. This implies a rather substantial processing capability and a considerable load on the ADCS. It is certainly not too soon to begin serious consideration of implementing the Pilot System.



AIRCRAFT PROGRAM PROJECTION

FIGURE 4-5.

SECTION 5

SYSTEM PHILOSOPHY

FOREWORD

The correlation problem was described in some detail in Section 1.1 In general, a statement of the problem consists of a description of the system inputs and the required outputs. However, acceptable solutions are further constrained by a body of somewhat arbitrary factors determined primarily by the experience of the investigator. This experience includes technical matters, cost effectiveness and his knowledge of those who will use the system output. These additional, but not stipulated, constraints can be conveniently classified as System Philosophy and will be discussed in this section.

SECTION 5 CONTENTS

SECTION 5 CONTENTS (cont.)

5.1 SYSTEM APPLICATIONS

Although not specified as part of the present contract, intended system applications must be considered in any attempt to solve the correlation problem. Correlation is obviously a question of degree, and the quality of a given solution can only be judged in terms of the application requirement. In turn, applications may best be considered in terms of the System-Human interfaces. Two classes of people determine the application criteria and, for clarification, they must be defined. They are the Experimenters and the Data Users.

5.1.1 The Experimenters

The experimenters are primarily interested in investigating equipment and techniques rather than in the subject material of the survey. Hence they will be evaluating sensors and processors, selecting wavelength bands for maximum descrimination or isolating dominant and secondary recognition factors. Their correlation requirements will run the gamut, but the emphasis will be on data-data correlation rather than on the necessity for tying a given datum to a specific ground coordinate system. The requirement for good data-data correlation between different sensors may be quite strong, however, and if it is found that the easiest means for achieving this is through earth-surface detail, data-ground correlation techniques may become important.

5.1.2 The Data Users

The ultimate purpose of the Earth Resources Program is the systems management of the Earth's resources through the use of remotely-sensed data. Hence the requirements of the data users are of paramount interest.

Basically, the correlation requirements are of the same order as the resolution requirements. For a study of "land use", a resolution cell 100 feet square may be adequate. This would permit a state government to determine the portion of its land being used for agriculture, rangeland, reservoirs, forests, urban areas etc. For this purpose data-data and data-ground correlation accuracy of 100 feet would be acceptable and such refinements as the generation of orthophotos or accurate grid matching would be quite unwarranted. Resolution/correlation requirements for the discovery of geological structures, snow cover, or ocean currents are similar or even less stringent. However, for the time-history of crop stress or yield prediction, resolution (and, hence, correlation) of a few feet may well be required.

Although it is recognized that virtually every user will continually request better and better data, Figure 4-2 gives a fair approximation of initial demands for resolution as a function of discipline. For the present, these same numbers can be taken as the required registration or correlation accuracies.

5.1.3 The Flexible Correlation Facility

Based on the preceding discussion, it is apparent that correlation requirements will vary widely, as a function of the end use of the data. Furthermore, at any point in the evolution of the Data Processing Facility, the system throughput will be a very sensitive function of the correlation accuracy demanded. Not only does the quantity of data increase as the square of the required accuracy (because of the area nature of the problem) but the increase is many times greater than this due to the necessity for finer and finer techniques. For gross correlation, it may be adequate to rectify the imagery for "taking" conditions and to make the simple trigonometric corrections for predictable nonlinear sweeps. As the correlation cell decreases in size, random nonlinear sweeps must be compensated and, with a further decrease in cell size, perspective distortion due to terrain relief must be taken into account. Each of these successive techniques will increase the processing time manyfold, so that the time required for three-foot correlation versus one hundred-foot correlation increases, not by a factor of one thousand (the cell rate) but, more likely, by millions.

The only possible conclusion which can be reached from the above argument is that a single inflexible correlation system must be either grossly inefficient or totally inadequate. The resulting philosophy, therefore, dictates the necessity for a flexible system capable of providing the most exacting correlation possible, but also possessing the necessary screening and bypassing functions to permit correlation to only the degree of accuracy warranted by the specific problem.

5.1.4 System Products

Although the present contract is not directly concerned with ultimate system products, it behooves the correlator designer to ensure that he does nothing which will degrade those products. System products may include tabular and coded computer printouts resulting from automatic

analysis, but they will also include various types of pictorial maps. The classical "false" color display or hard copy is exemplary of this type of output product. It consists of a maplike representation of an area wherein all elements having common characteristics are presented in a given color. Thus, vegetated areas might appear green; sand and rock, brown; water, black; and urban areas, red.

Where automatic identification techniques are not yet feasible, photo-interpreters may be required and, even where automation does perform the identification, many users and experimenters will still desire to examine the imagery. Hence another system product will be selected pristine imagery from any of the imaging sensors. It is an element of System Philosophy that all such imagery will suffer an absolute minimum of degradation in passing through the correlation system. In summary, the System Philosophy is as follows:

--- Provide a means for obtaining a high degree of correlation for the least correlatable data.

--- Provide the necessary bypasses to permit correlation only to the degree necessitated by the input data and required by the users.

--- Take the user requirements on correlation to be the same as his resolution requirements.

--- Provide a means for correlating imagery (photographic, line-scanned and radar) without degrading its information content.

5.2 EARTH RESOURCES STANDARD COORDINATE SYSTEM

In the Statement of Work, Section III, task 8 says,

"Investigate and recommend a meaningful coordinate system on the Earth's surface to which the data are to be translated."

This requirement could be considered adequate justification for deriving such a coordinate system, but it is of interest to consider the

reasons for the requirement and the manner in which the system will be used.

First, it should be observed that a universal standard coordinate system is not absolutely essential to the design and operation of a successful Earth Resources System. It would be quite possible to reference the location of any set of data to well known and readily identifiable landmarks. Thus a given set might be defined as extending North 10 nm & East 20 nm from the Route N bridge over the A river. This would permit the identification of every ground element (of say 100' x 100') within the set and the subsequent signature extraction of the elements through the use of several sets of data covering the same (or overlapping) areas. For simplicity (and because a data set covers only a small part of the Earth's surface) the elemental positions would probably be given in a plane tangent to the surface at the reference point, and in rectangular coordinates. Such a system has been used frequently in the past for purposes of land grants or locating specific areas in the wilderness etc. and it could certainly be used for the present purpose.

What would happen if this tangent-plane approach were used in the E.R. System? Clearly we would constantly accumulate more and more 0, 0 points. Eventually, observed areas would overlap and the resolution cells would not be congruent and a given cell would have more than one designation. A given cell in two different data sets would be represented in two non co-planar sets of coordinates and complex transformations would be necessary in the correlation processing.

Consideration of the requirements and use of a standard coordinate system has led to the following set of criteria:

1) Every elemental area of the Earth's surface should be uniquely identifiable.

2) A single set of coordinates should be used to cover the entire earth.

3) The coordinate system should be orthogonal and, if possible, Cartesian for small areas.

4) All elemental areas should be approximately the same size.

5) Convenient super-and sub-elements should be easily definable.

6) All other things being equal, special consideration should be given to standard or familiar coordinate systems.

There are probably other criteria, and the weighting of the above six would prove to be a matter of personal preference. Nevertheless, it is believed that most knowledgeble students of the subject will appreciate the significance of these, and they will therefore be used in the following discussion.

Considerable thought has been given to the evaluation of possible coordinate systems in the light of these criteria and it is believed that one system uniquely satisfies the first three. This is the familiar geographical coordinate system of latitude and longitude.

In particular, it is suggested that the geodetic terrestrial coordinates be used. These are based on the local normal to the spheroid and the axis of rotation and are the ones universally used for charting. The longitude of a point on the surface is defined as the angle between the reference meridonal plane (the plane containing the earth's axis and Greenwich) and the meridonal plane containing the point in question (usually measured to the westward). The latitude of a surface point is defined as the angle between the equatorial plane and a line normal to the spheroidal surface at the point in question.

The suggested coordinate system will now be tested against the above listed criteria.

1) Every point on the earth's surface has a single and unique set of coordinates.

2) The suggested coordinates are world-wide so that only two numbers are required to identify uniquely any point on the surface.

3) The system is orthogonal. Furthermore, it is by far the simplest and most elegant set of orthogonal coordinates inscribable on a near-spherical surface.

4) It is quite possible to meet the requirement that all cells be approximately the same size, but this item will be discussed in detail later.

5) Super- and sub-cells represent no problem, but should be correlated with item (4) above. This correlation will probably indicate the desirability of making super- and sub-cells on the basis of powers of 2 relative to the standard element.

6) Clearly the geographical coordinates represent a standard and familiar system.

Once the philosophy of the use of geographical coordinates is adopted, the details of implementation must be derived. Again it seems advisable to adopt the results of earlier work, both because those results are the best available and because they are familiar to many workers in the field.

In 1930, the U.S. Coast and Geodetic Survey adopted, in Special Publication No. 5, Clarke's Spheroid as the official figure of the earth and established equations for the size of one degree of latitude and longitude. These are:

$$M^\circ = 111,132.09 - 566.05 \cos 2\phi + 1.20 \cos 4\phi - 0.002 \cos 6\phi + \cdots$$

$$P^\circ = 111,415.13 \cos \phi - 94.55 \cos 3\phi + 0.12 \cos 5\phi - \cdots$$

where

M° is the length in meters of one degree in latitude (along a meridian)

P° is the length in meters of one degree in longitude (along a parallel)

ϕ is the mid latitude of the degree being calculated.

These equations have been solved and tables such as the one shown in Figure 5-1* are available. At the equator, one second of latitude is equal to 100.76 feet and one second of longitude equals 101.45 feet. Since 100 feet is a convenient elemental size, it is suggested that the basic element be designated as one second by one second for all areas between ±45° latitude (70% of the earth's surface). Figure 5-2 illustrates the situation in the vicinity of North Latitude 41°. The shaded element in the figure is uniquely identified as: N41°15'42" W 100°00'13". The fact that the cells vary in size and are not square should cause no difficulty, since it is anticipated that the appropriate grid will be superimposed on all pictorial data.

From 45° latitude to 70° latitude, the standard cell will be designated as one second in latitude by two seconds in longitude; from 70° to 80° the cell will be four seconds in longitude, etc. In general, when the ratio of cell width to cell height reduces to $1/\sqrt{2}$, the width will be doubled. Thus the aspect ratio is never different from a square by more than about 41%. Figure 5-3 shows the situation very near to the pole where the longitudinal dimension is 512 seconds of arc. It will be seen that even here, the cells are nearly Cartesian.

The reason for making the super- and sub-cells powers of two now becomes clear. If a survey crossed one of the "break point" parallels, the cells could still be kept essentially the same size by using double or half cells on one side of the boundary.

In determining the geographical coordinates of a point on the surface of the earth, the earth's figure is assumed (as for example, Clarke's spheroid) and astronomical measurements are made. Since these measurements involve the use of the gravity vector it is important that no gravitational anomalies exist (which may cause errors as large as one minute). Hence, for the establishment of a "Prime Datum" a point is selected where such anomalies are minimum. The North American Datum (1927) is located in the center of Kansas and is called Meade's Ranch. Its coordinates are:

Latitude: 39° 13' 26.686" N

Longitude: 98° 32' 30.506" W

* American Practical Navigator - Bowditch 1962 pg. 1245

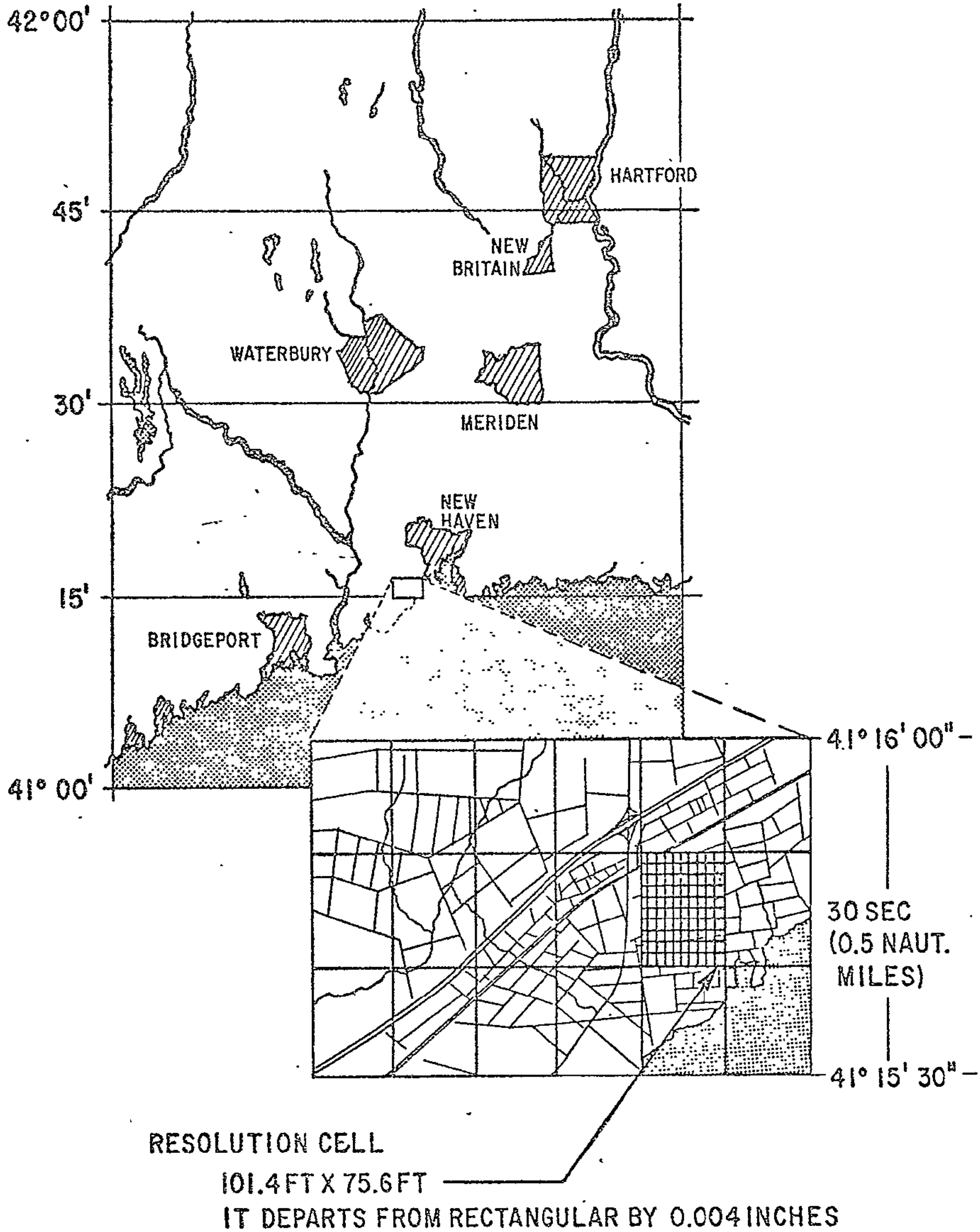
TABLE 6

Length of a Degree of Latitude and Longitude

Lat.	Degree of latitude: Nautical miles	Statute miles	Feet	Meters	Degree of longitude: Nautical miles	Statute miles	Feet	Meters	Lat.
°									°
45	60. 006	69. 054	364 603	111 131	42. 575	48. 994	258 691	78 849	45
46	. 017	. 066	669	151	41. 828	48. 135	254 154	77 466	46
47	. 027	. 078	731	170	41. 068	47. 260	249 534	76 058	47
48	. 038	. 090	797	190	40. 296	46. 372	244 843	74 628	48
49	. 049	. 103	862	210	39. 511	45. 468	240 072	73 174	49
50	60. 059	69. 114	364 925	111 229	38. 714	44. 551	235 230	71 698	50
51	. 070	. 127	990	249	37. 905	43. 620	230 315	70 200	51
52	. 080	. 139	365 052	268	37. 084	42 676	225 328	68 680	52
53	. 090	. 151	115	287	36. 253	41. 719	220 276	67 140	53
54	. 100	. 162	177	306	35. 409	40. 748	215 151	65 578	54
55	60. 111	69. 174	365 240	111 325	34. 555	39. 765	209 961	63 996	55
56	. 120	. 185	299	343	33. 691	38 770	204 708	62 395	56
57	. 130	. 197	358	361	32. 815	37. 763	199 390	60 774	57
58	. 140	. 208	417	379	31. 930	36. 745	194 012	59 135	58
59	. 150	. 219	476	397	31. 036	35. 715	188 576	57 478	59
60	60. 159	69. 229	365 531	111 414	30. 131	34. 674	183 077	55 802	60
61	. 168	. 241	591	432	29. 217	33. 622	177 526	54 110	61
62	. 177	. 251	643	448	28. 294	32. 560	171 916	52 400	62
63	. 186	. 261	696	464	27. 362	31. 488	166 257	50 675	63
64	. 194	. 270	748	480	26. 422	30. 406	160 545	48 934	64
65	60. 203	69. 280	365 801	111 496	25. 474	29. 314	154 780	47 177	65
66	. 211	. 290	850	511	24. 518	28 215	148 973	45 407	66
67	. 219	. 298	896	525	23. 554	27. 105	143 117	43 622	67
68	. 226	. 307	942	539	22. 583	25. 988	137 215	41 823	68
69	. 234	. 316	988	553	21. 605	24. 862	131 273	10 012	69
70	60. 241	69. 324	366 030	111 566	20. 620	23 729	125 289	38 188	70
71	. 247	. 331	070	578	19. 629	22 589	119 268	36 353	71
72	. 254	. 339	109	590	18. 632	21. 441	113 209	34 506	72
73	. 260	. 346	148	602	17. 629	20. 287	107 113	32 648	73
74	. 266	. 353	184	613	16. 620	19. 126	100 988	30 781	74
75	60. 272	69. 359	366 217	111 623	15. 606	17. 959	94 826	28 903	75
76	. 276	. 365	247	632	14. 588	16. 788	88 638	27 017	76
77	. 282	. 371	280	642	13. 565	15. 611	82 425	25 123	77
78	. 286	. 376	306	650	12. 538	14. 428	76 181	23 220	78
79	. 290	. 381	332	658	11. 507	13. 242	69 918	21 311	79
80	60. 294	69. 385	366 355	111 665	10. 472	12. 051	63 629	19 394	80
81	. 298	. 389	375	671	9. 434	10. 857	57 323	17 472	81
82	. 301	. 393	394	677	8. 394	9. 659	51 001	15 545	82
83	. 303	. 396	411	682	7. 350	8. 458	44 659	13 612	83
84	. 306	. 399	427	687	6 304	7. 255	38 304	11 675	84
85	60. 308	69. 402	366 440	111 691	5. 256	6. 049	31 939	9 735	85
86	. 310	. 403	450	694	4. 207	4. 842	25 564	7 792	86
87	. 311	. 405	457	696	3. 157	3. 633	19 180	5 846	87
88	. 312	. 406	463	698	2. 105	2. 422	12 789	3 898	88
89	. 313	. 407	467	699	1. 052	1. 211	6 394	1 949	89
90	60. 313	69. 407	366 467	111 699	0. 000	0. 000	0	0	90

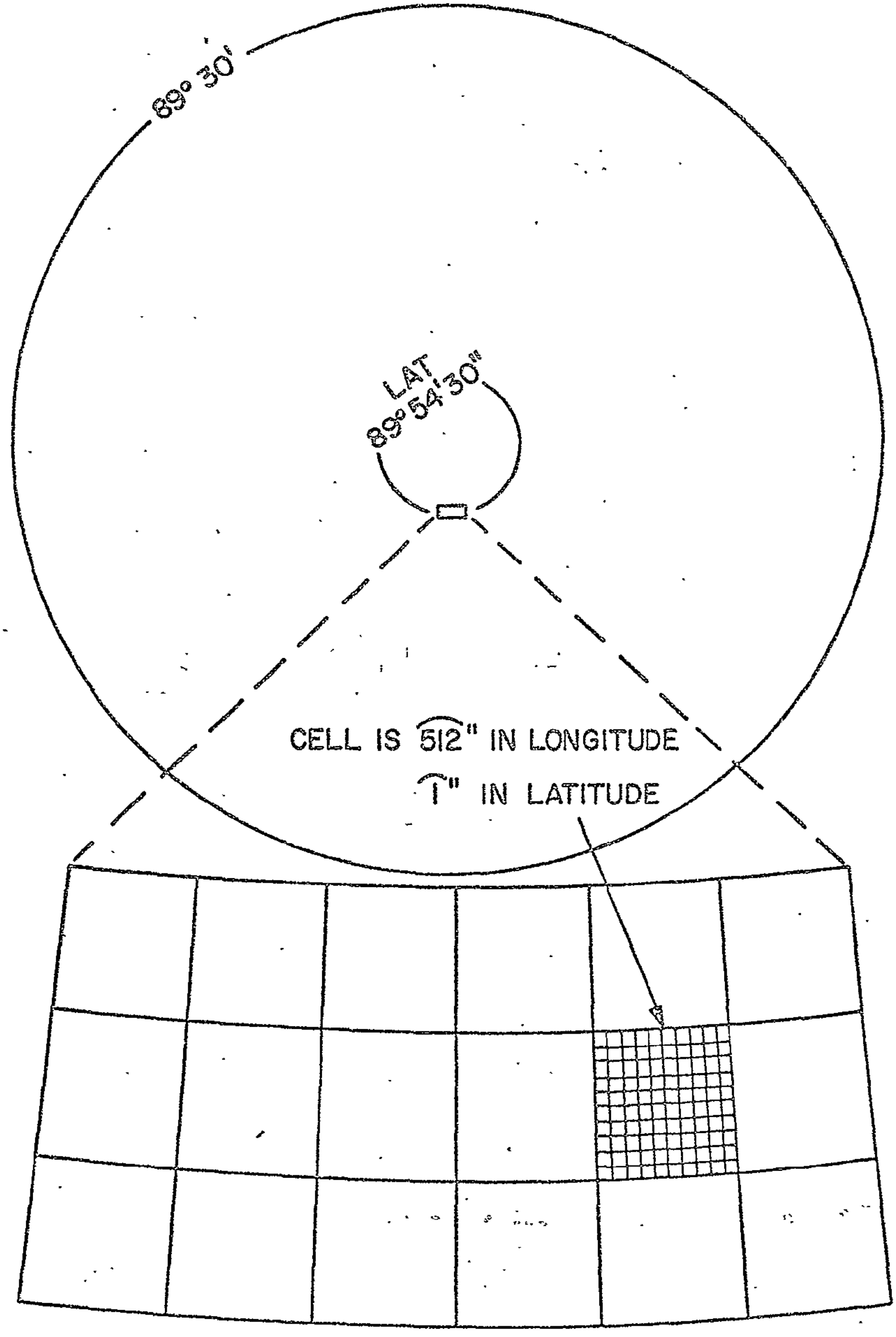
LENGTH OF A DEGREE OF LATITUDE AND LONGITUDE

FIGURE 5-1.



RESOLUTION CELLS AT 41° LATITUDE

FIGURE 5-2.



RESOLUTION CELLS 5.5 N.M. FROM NORTH POLE

FIGURE 5-3.

Other Prime Datums exist throughout the world (as the Tokyo Datum) and are not necessarily coherent with this one. However, in general, this fact causes no inconvenience since each is used for its local standard.

"Local", as used here may involve a very large area, such as the North American Continent, and areas referenced to different Datums are usually separated by oceans or other unpopulated areas. There were formerly many more Prime Datums, but they are gradually being tied together so that, eventually, all points on the earth's surface will be accurately located with reference to the Greenwich meridian and the equator.

The establishment of a horizontal control network covering the United States or the North American Continent, starting from the Prime Datum, is a complex task involving all the arts of surveying and photogrammetry. However, this task is being constantly pursued and the extent and precision of such a network is continually increasing. It is patently impossible to label a given ground element with greater accuracy than the accuracy (relative to the North American Datum) of the nearest available first, second or third order control point. Since this accuracy is finite, the problem of overlapping survey areas will still exist and a lack of congruence of a given ground cell on two different surveys may appear. Ultimately, this problem will be resolved by more accurate datums, but in the meantime it will be necessary for the Automatic Data Correlation System to reconcile the several overlapping surveys and arrive at a unique designation for each ground cell. This should be done as the problem arises, but a standard technique of reconciliation must be developed.

It is well recognized that the proposed coordinate system is not the only acceptable one. Of the several alternative contenders, the Military Grid on the Universal Transverse Mercator projection is probably the strongest. And here, a distinction should be made bwtween Coordinate Systems and Projection Systems. A coordinate system is simply a means for uniquely identifying every point on the Earth's surface whereas a projection system is a means for portraying a portion of the spherical Earth's surface on a plane. Hence, the selection of one does not prejudice the other. If, for example, the proposed geographical coordinate system is chosen, any desired projection

(including the transverse Mercator) can be used by the simple extension of the density of the meridians and parallels.

The primary advantage of the Military Grid - UTM approach is that the basic cells are squares. However, because it is impossible to project a significant portion of a sphere onto a plane (or a cylinder) without distortion, it is necessary to divide the Earth up into many zones. The zone separators are meridians and, at the zone boundaries, partial squares of various sizes and shapes exist. Furthermore the cells in one zone are not parallel with those in the adjacent zone and the angle between them is a function of latitude as illustrated on Figure 5-4. This means that if a survey happened to overlap two zones, the resulting grid pattern would be drastically different from the desired Cartesian coordinates.

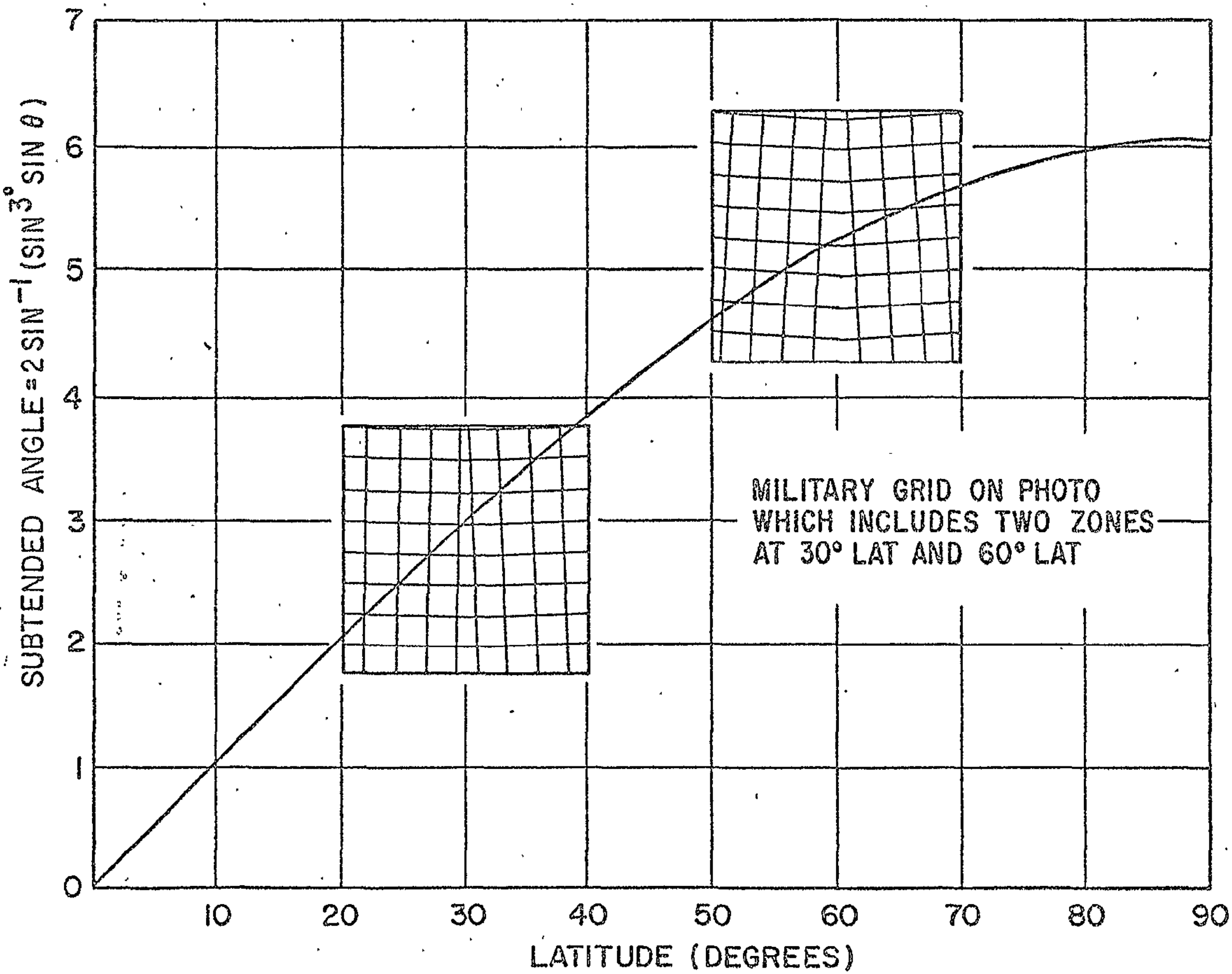
5.2.1 Coordinate System Summary

It cannot be emphasized too strongly that the choice of a particular ground coordinate system is not critical to the success of the Earth Resources Program. However, at the present time, the program is in its infancy and it would be unfortunate to burden it with a contrived coordinate system. The earth is roughly spherical; the completely natural geographical coordinate system is known and understood by workers in all fields; tables relating these coordinates to linear distances are universally available; and the computer art has reduced numerical calculations to a trivial problem.

If a standard Earth Resources coordinate system is to be adopted at this time, it would be difficult to justify any system other than the geographic one.

5.3 APPROACHES TO CORRELATION

It has been observed that correlation is a relative matter and that the difficulty of the problem is a function of the accuracy of the input data and the requirements placed on the output data. It has also been noted that, once the most general problem has been solved, appropriate shortcuts can readily be introduced for the simpler problems. Unfortunately, these statements simply lead to another question: how does one determine



BOUNDARY ANOMALIES IN MILITARY GRID

FIGURE 5-4.

the degree of processing required or justified for a given set of data? A specific answer to this question cannot be given at this time. Along with the system, the answer will evolve as a result of experience. Guidelines can be obtained from information of the type contained in Figure 4-2, but it will be noted that "timber inventory" (for example) ranges from 5 feet to 100 feet required resolution. Since a modest amount of experience will resolve this type of question for a large number of problems, whereas a large amount of theoretical analysis may not, the former approach is recommended. Accordingly, this section will be devoted to an examination of possible solutions to the most general condition.

This condition involves two or more images having the following characteristics:

--- They were acquired from different vantage points at different times with different sensors mounted on different platforms.

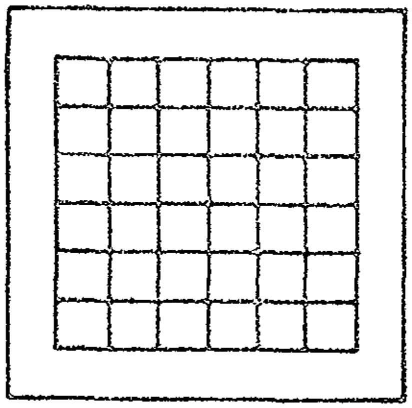
--- They, therefore, possess three basic types of differential planimetric distortion due to:

- the average attitude of the sensor when the imagery was acquired.

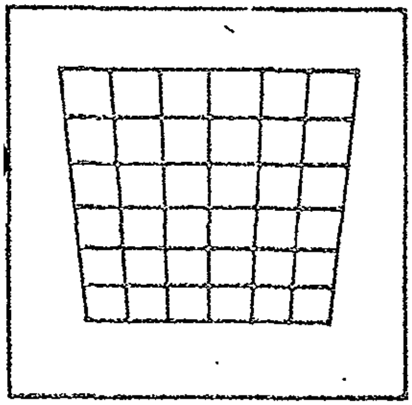
- the varying attitude of the sensor during acquisition, and the sensor characteristics

- the terrain relief.

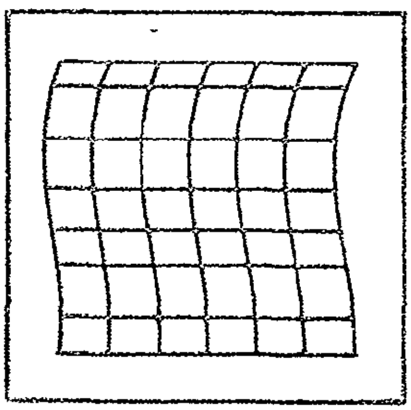
The first of these, the average attitude will result in a simple regular distortion which can be readily removed by classical area-type rectification techniques. The second type, due to a known varying attitude or regular nonlinear sweeps, is of a semirandom nature requiring a much more complicated point-by-point rectification. The third type is completely random and rectification without a detailed knowledge of the terrain is virtually impossible. The three conditions are illustrated in Figure 5-5. Obviously the conditions shown in parts (c) and (d) may exist simultaneously. The problem of removing these types of distortion, so that correlation can be realized, represents three different orders of magnitude in difficulty.



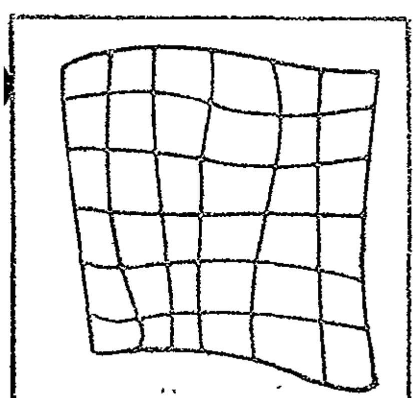
(a) THIS REPRESENTS A PICTURE OF A RECTANGULAR GRID ON THE EARTHS SURFACE. THE SURFACE IS LEVEL AND THE CAMERA AXIS IS PERPENDICULAR TO THE SURFACE. THE AIRCRAFT ALTITUDE IS 4000 FT. AND THE GRID SQUARES ARE 1000 FT. ON A SIDE.



(b) HERE, THE CAMERA AXIS WAS TILTED 5°. THE PICTURE IS A SNAPSHOT, I. E. THE ENTIRE PICTURE WAS TAKEN WITH THE CAMERA IN A FIXED ORIENTATION. THIS DISTORTION IS READILY REMOVED BY CLASSICAL RECTIFICATION IF THE MAGNITUDE AND DIRECTION OF THE TILT ANGLE ARE KNOWN.



(c) THIS REPRESENTS THE CONDITION FOR A LINE-SCAN SENSOR WHERE THE SENSOR AXIS IS VARYING IN PITCH AND ROLL DURING ACQUISITION. DISTORTION REMOVAL IS MUCH MORE COMPLEX AND TEDIUS. IN ADDITION, A SECOND DISTORTION MAY BE PRESENT DUE TO NON-LINEAR SCANNING.



(d) THIS IS THE GENERAL SITUATION WHERE THE SURFACE IS NOT PLANE. MAXIMUM ELEVATION DIFFERENCE IS 500 FT. BETWEEN THE LOWER LEFT AND RIGHT HAND CORNERS (A DISTANCE OF 6000 FT). DISTORTION REMOVAL REQUIRES A COMPLETE KNOWLEDGE OF THE TERRAIN RELIEF OR THE USE OF AN ORTHOPHETO AND VIDEO CORRELATION TECHNIQUES.

DISTORTION CAUSED BY "TAKING" CONDITIONS

FIGURE 5-5.

5.3.1 Stabilization

If the platforms could be perfectly controlled the first two problems would be solved. However, in practice, the control is less than perfect. Figure 4-3 indicated the effect on ground accuracy and, hence, on correlation of the control accuracy. By combining the information in Figures 4-2 and 4-3 with data on the state-of-the-art of stabilization and of navigational accuracy, the question of degree of processing required can theoretically be answered. Although this answer would have to be experimentally verified, it is nevertheless interesting to examine the theoretical approach.

As an example, consider the automatic monitoring of the progress of a stress condition acting on a specific tree type. The area is overflown once per month during the summer and the condition is identifiable from the signature derived from a multispectral scanner. In order to observe progress, it is necessary to correlate specific trees from one record to a succeeding one. Judging from the size of the trees, it might be concluded that ten foot correlation would be adequate. Furthermore, the navigational accuracy provides knowledge of position to within five feet (in three dimensions) and the sensor mount provides verticality to within 0.25 degrees (4 mr.). If the flight were maintained below 2000 feet and the scans were accurately controlled and corrected, it is probably that correlation could be automatically achieved using only the navigational and mount information.

The preceding paragraph is simply a statement of the control necessary to determine, without recourse to ground detail, the correlation between sensor records (or between a given record and the ground) within ten feet. It will be appreciated that the necessary control is quite stringent. Furthermore, if one wished to fly higher, or if the correlation cell were smaller, or if the navigation system were slightly looser, this method would fail.

On the other hand, if the correlation requirement were less stringent this method would be entirely adequate. A separate study should be conducted to define more completely exactly which problems can be solved by the stable mount/accurate navigation approach. In any event, it is obvious that it is not a solution to the most general problem.

5.3.2 Corrections from Navigational Data

For conditions where it is impossible to control the sensor attitude and location to the desired degree, it may still be possible to obtain a continuous accurate measurement of these parameters. If so, it is theoretically possible to correct the pictorial data at a later time. For the case of a frame-type exposure, this is a relatively simple task involving only proven rectification techniques. For line scan data with its "rubber sheet" distortion and nonlinear scan, the problem is greatly aggravated, and, for areas containing significant relief, this approach is quite impractical.

5.3.3 Resectioning

When neither the control nor the error information is adequate to produce the required ground accuracy, the technique of "resectioning" may be used. Again, for frame-type imagery this is straightforward, relatively simple and quite accurate. It requires three or more known points on the surface which can be accurately located in the photograph. By accurately measuring their separation on the photo and using this information in conjunction with the known three-dimensional location of the ground points, the original taking conditions can be determined. Once this has been done, rectification proceeds normally.

As in the preceeding section, life is considerably more complicated when this technique is applied to line-scan imagery. Since only small areas of the picture may be considered to have been acquired under a given taking condition, it is necessary to construct a large number of space pyramids and attempt to reconstruct the original flight path together with the vehicular gyrations. Not only does this require many ground control points, but, because of the necessarily short base lines, the pyramid construction is of dubious accuracy. Add to this the fact that it is never really certain that the vehicular attitude was, in fact, stable during the recording of a set of three points, and it becomes obvious that the resectioning of line-scan imagery is highly questionable.

5.3.4 The Orthophoto And Small Area Correlation

Although the techniques thus far described may prove adequate for certain applications, they certainly will not solve the general problem outlined in paragraph 5.3. Aside from the several error sources noted

in each case, it will be observed that the problem of perspective distortion due to terrain relief has been virtually completely ignored.

If a human is given the task of visually correlating two images, he uses none of the preceding techniques. Instead, he studies the small area detail, locating such features as roads, buildings, rivers, lakes, and all manner of natural and man-made clues. By so doing he is able to divide the images into arbitrarily small cells and determine a one-to-one correspondence between the two sets. It is of the greatest importance that he can accomplish this irrespective of a very large class of distortions. About the only constraint is that the two images be topologically identical i.e., that a given cell on one of the images is contiguous with the same set of cells as its corresponding cell on the other image. Hence, this set of distortions includes the complex cases of rubber-sheet distortion due to vehicular gyrations or nonlinear non-regular scans, and the random distortions due to terrain relief, or any combination thereof.

Fortunately, recent advances in the arts of photogrammetry and video correlation now make it entirely practical to duplicate this highly complex human capability by automatic means. Modern orthophotoscopes, without human intervention and with a remarkable degree of leniency in taking conditions, produce planimetrically correct orthophotos from overlapping aerial imagery. Once this is accomplished, the video correlator permits tracking any other uncorrected imagery with the orthophoto.

This capability permits the use of a variety of processing techniques. A rectangular grid on the orthophoto can be transferred to a ground-coherent curvilinear grid on pristine imagery. If this is done on several images of the same area, automatic correlation becomes a matter of automatic cell counting without any consideration of relative distortions. Alternatively, a video-correlator-scanner controlled by an orthophoto could be made to read out the elemental densities of an uncorrected image at uniform planimetric intervals for storage on tape, to be correlated with other similar tapes, or for reconstruction of a fully corrected image. If desired, multi-spectral orthophotos could be generated in this manner.

Obviously, the foregoing represents the ideal solution, but, unfortunately, a couple of cautionary notes are in order. First, the production of orthophotos is, currently, a fairly expensive and time-consuming operation, requiring of the order of two hours to produce a single 9" frame. This objection is partly compensated by the fact that once an orthophoto is generated

it can be used as a control for that area from then on. And it is certainly desirable, for many reasons, to start building up a library of orthophotos.

The second question concerns the correlatability of imagery taken at widely separated parts of the spectrum. Excellent correlation has been demonstrated for simultaneously exposed multispectral photography. Although the images differed significantly in density distribution, this test is hardly conclusive. Similar tests should be conducted using line-scan near-and far-IR imagery and side-looking radar images versus photographs. It may prove necessary to modify the exact nature of the correlation process for these more difficult tasks but, since the human experiences little difficulty in correlating such images, it should certainly prove feasible to accomplish it automatically. A small study effort designed to resolve this question will be initiated early in Fiscal 1971.

5.4 SYSTEM EVOLUTION

Everything, both natural and manmade, evolves from simple systems to increasingly complex ones. Uncontrolled evolution has produced the tremendous variety of extremely complex natural systems existing today. But it took billions of years and, probably, millions of dead ends.

Artificial systems follow similar evolutionary paths. Each new step is based on an improvement in the present system for the purpose of solving an existing problem or for adaptation to a changing environment. Nature seems destined to follow this shortsighted path, but mankind is making an effort to improve on it.

The technique of directed or guided evolution is straightforward. An attempt is made, using the best available information and brainpower, to estimate the most probable functional problems at some future date. Next a "system" consisting of management, techniques, hardware and software is designed to solve the immediate problem, but constrained by the requirement that no component of this system may prove inimical to the solution of the predicted problems. This embryonic system is then fabricated and evolution is permitted, but only in directions which will contribute to the anticipated advanced system.

This is directed evolution. It is necessary, simply because the predicted future problems cannot be solved at this time. As the technological environment changes in products, ideas, computing capability, and software new methods will appear and the optimum solution to future problems will constantly change. Thus the embryonic system must evolve toward the envisioned advanced system. But this is not enough. Just as the problem-solving ability evolves so, too, do the problems. The advanced system was based on predicted functional requirements. What appear, today, to be the most probable problems of the next decade may change drastically long before that decade arrives. Clearly, if these changes could be predicted, the preceding statement would be untrue; but recent history guarantees that they will occur, and recognition of this fact may permit the avoidance of some pitfalls.

In summary, the concept of directed evolution is based on a very complex feedback loop involving the following continuously changing elements:

-- An accurate evaluation of present requirements.

-- The best possible educated guess of future requirements.

-- A continuous knowledge of the state of all pertinent arts.

-- The management ability, wisdom and authority to permit and promote a variety of evolutionary steps, but to reduce the probability of any of them leading the system into blind alleys.

5.4.1 Philosophy Implementation

It is difficult to find fault with the generalized concepts outlined in the previous section, but their practical implementation is another matter. Here, there is bound to be disagreement as to the most probable future requirements, the most probable technological developments and the optimum organizational structure for dealing with these developments. Despite claims to objectivity, planners will be influenced by their individual experience, diverse specialized knowledge and personal intuition. It must be recognized that many paths may lead to the same goal.

Accordingly, the authors, in submitting their concept of the directed evolutionary Earth Resources Processing Center, make no claim to uniqueness.

5.4.2 The Evolutionary Program

In accordance with the described philosophy, Fairchild engineers interviewed members of the User community, representatives of the several pertinent technological arts and personnel of the cognizant government agencies. As a result of these discussions, a tentative model of the probable requirements and capabilities for the latter half of the present decade was formed. Next, a functional system was designed which, if implemented, could presumably fulfill the predicted requirements. At this point it was neither possible nor desirable to reduce the functional system to practice. It was impossible because, in some cases, no known methods for performing the indicated functions exist. It was undesirable because the requirements will almost certainly change before 1975. Nevertheless, this functional system will serve admirably as a tentative evolutionary goal in the design and fabrication of earlier systems.

Ground processing of remotely sensed Earth Resources data does not start at this point in time. For the past several years, many experimenters have been developing techniques and equipment to perform specialized tasks. But, in general, the evolution has been largely undirected.

5.4.2.1 Pilot Configuration

The Pilot System is described in detail in Volume I Section 2. From a philosophical viewpoint, it is intended to be a direct progenitor of the advanced system which, at present, is described largely in functional terms only. As such, the Pilot System is capable of performing virtually all of the functions envisioned for the advanced system, but with a primitive capability. For example, it is a "walk-through" collection of system components rather than a single integrated automatic system. It is intended to demonstrate the capabilities of its descendent without actually duplicating them. And just as a natural progenitor can produce a wide variety of descendents, so too can the Pilot System. The difference is that, whereas the natural progenitor does just that, the directed evolutionary process will, hopefully, continually produce the currently optimum system.

5.4.2.2 The Intermediate Point

This is probably a sequence of points in time rather than a unique one. It represents a concept of system-integration where formerly separated functions are tied together with appropriate input-output devices. Whereas the primary function of the Pilot System was demonstration of feasibility, the Intermediate System will start to have an operational function. Data management will assume an increasing role and throughput rates will be measured and predicted.

As the evolution from an experimental system to an operational one progresses, the requirements on future generations must be continuously re-determined and the evolutionary process re-directed.

5.4.2.3 The Complete System

It will be appreciated by now that the word "Complete" should be in quotes. It represents what, today, appears to be the most probable evolutionary goal, and is described in Volume II, Sections 7, 8, 9 and 10. An examination of these sections will reveal the fact that the anticipated problems and requirements have been investigated in considerable depth and that the resulting system has been functionally designed in detail. However, it should be emphasized again that the requirements are anticipated ones and that they will probably be significantly modified by the time this generation of Data Processing Facility is implemented.

5.5 PROCESSING CONTROL

The general approach to data correlation, and the evolution from Pilot System to more advanced versions has been discussed. It remains to consider the management of data processing through these systems.

In line with the ideas expressed in the previous section, processing control will begin to assume significant importance at the "Intermediate Point" of system evolution. At this point production, rather than feasibility, becomes of interest; system loading increases; and the requirement for consistent, reliable throughput becomes dominant. The corresponding control subsystem must first be conceived in terms of the complete operational system, then simplified for the Pilot System. This will assure that it contains all the essential elements to permit it to grow along the appropriate lines, as the system evolves...

5.5.1 Scheduling

Because the data available for processing will probably always exceed the processing capability, the first task of a well designed Management Information System (MIS) is to assist in production scheduling. This will operate as a closed loop system and will consist of three basic components.

5.5.1.1 Mission Plan and Mission File

The data processing manager will participate in mission planning in the interest of efficiency. His primary function will probably be that of dampening the ardor of over-enthusiastic experimenters and potential users by advising them, early, of the rate and loading of his facility. This precaution will prove more satisfactory all around than if the users go to the expense of collecting great quantities of data only to be told, after the fact, that only a miniscule portion of it can be processed.

Once the mission plan has been agreed upon, the control manager will enter it into a general file to be used as one of the inputs to the scheduling function.

5.5.1.2 Flow Model

The second factor governing scheduling is the status of the flow model. This is a computer model of the complete system containing frequently updated information on the equipment status, load and backlog. Despite the best planned scheduling, the established priorities will require modification whenever an emergency such as a flood or hurricane occurs. Emergencies may also be caused by the breakdown of a portion of the system. Information available from the flow model will be used for rescheduling with a minimum of disruption.

5.5.1.3 Traffic Display

This will be a combination graphic plus alpha-numeric cathode ray tube display. It will provide the processing controller with the capability for calling up for examination any type of information within the flow model in either graphic or A/N form. As a growth item, he should also be able to call up and view pictorial data at various stages of processing, if system complexity warrants it.

5.5.1.4 The Feedback Loop

The processing controller closes the scheduling loop by using the information presented on the Traffic Display to control the system input. In a longer range sense, he will also use the experience gained from the entire system operation to improve scheduling and control and even to guide system development.

5.5.2 Data Monitoring

The necessity for screening and routing the potentially large quantity of input data has been emphasized. This will occur not only at the system input, but also at critical work stations within the system.

5.5.2.1 Process Planning

This function starts at the time of Mission Planning and, as previously noted, is actually a factor in determining the mission scope and parameters. Once the mission data has been acquired, it will be given a preliminary screening to determine its technical quality and its applicability for the intended purpose. Based on the results of this screening the detailed processing requirements will be established and the data will be entered into the appropriate processing flow paths. The first result will be an immediate updating of the Traffic Flow model. If all conditions are satisfactory, mission data processing will begin.

5.5.2.2 Monitor Points

At a number of points throughout the processing cycle, the mission data will be monitored. This will probably be done on a sampling basis and will serve two purposes. The first of these is simply to assure the processing manager that the system is operating properly and the second is to assure the Experimenter or User that his processing program is working as planned. If a negative answer is obtained to either of these questions, processing of these data will stop at this point, thereby freeing the system for other work while this specific problem is being re-evaluated.

5.5.2.3 Closed Circuit Television Network

As the processing system evolves, it may become extensive and complicated. If that occurs, the Monitor Points can be linked up with each other and with other stations of the Management Control system

by means of closed circuit television. A fairly complex, switchable network is envisioned, which will permit selective monitoring of the data at a number of locations. Again, the basic purpose of this subsystem is screening and re-routing to ensure that no processing time is wasted on improper functions or inadequate data.

5.5.3 Work Station Elements

No attempt will be made to design any Work Stations in detail at this point. However, certain components and functions are definable now, in general terms.

5.5.3.1 Code Block Reader

Every frame of film passing through the system will contain a standard code matrix identifying the mission, flight number, frame and time of exposure together with pertinent navigational information, etc. Each Work Station will have a code block reader to translate these data to computer-compatible form for entry into the Management System.

5.5.3.2 Status Indicator

Ideally, each equipment should contain automatic circuits which continuously monitor the status of the unit and present it to the Management System. Typical indications would be---Ready---Busy---Off---Down/Major---Down/Minor. The "trouble" indications would be accompanied by alerting signals such as flashing lights; and the Major/Minor decisions might be operator entries via switch positions.

5.5.3.3 Cathode Ray Tube A/N Terminal

This interacting display will permit the operator to call up processing instructions or auxiliary information for the data then being processed. It will also permit him to enter decisions relative to subsequent processing and/or rerouting. In general, along with other Work Station elements and the over all Processing Control system, the A/N terminal functions will evolve as experience dictates. It will be simplest to install these units initially only at certain critical Work Stations where data traffic is found to be heavy and/or complicated. However, it seems desirable that remote terminals eventually be available at every major functional station.

5.6 PHILOSOPHICAL SUMMARY

This concludes the discussion of the elements of System Philosophy considered most pertinent at this time.

In summary, the Philosophy constrains the conception and growth of the data processing system to an evolutionary form, but one in which each change is carefully directed toward the realization of a previously specified superior system. It is also recognized that, not only will the "superior system" evolve as a continuously unreachable goal, but that the expressed philosophy will, itself, be modified by increased experience and knowledge.

SECTION 6

COLLECTION CONTROL

FOREWORD

For truly productive correlation of the flight program mission products, it will be necessary to thoroughly standardize the operational methods and controls used throughout the entire program. This standardization will undoubtedly evolve in a gradual, piecemeal manner, with technical innovations being introduced only after they are proven in an R&D phase. Rigorous control will be required for all aspects of data collection, processing and dissemination in order to efficiently meet the user/experimenter needs for timely, accurate information.

In this section attention is directed to the first problem area, data collection control, since this is important in determining the data volume to be processed and the end-to-end geometric accuracy that can be achieved.

The components of collection control include material selection, film-batch sampling, environmental control, sensor control, data sampling, and the adherence to critical mission parameters. The following discussion will cover in detail these items, all of which can produce errors that may or may not be tolerable in meeting the overall accuracy goals of the correlation process.

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(Cont'd.)

ILLUSTRATIONS PAGE

TABLES

6.1 SELECTION OF MATERIALS

The first collection control item that warrants discussion is the selection of materials that will be used to record the mission data; these include films, filters and magnetic tapes. For photographic film, before a choice of specific materials can be made, consideration must be given to the type of information that one expects to extract from the image.

In all cases, film image density is analyzed to determine its relationship to the natures and states of the radiating/reflecting objects on the terrain. Four distinctive collection techniques are available:

1) Over a period of time, the sensor collects full "natural" color images of the particular resource phenomena in their various states of maturity, decay, etc. A learning cycle is initiated to uncover the effects of variations in illumination, cloud cover, and season. Comparative analyses of the color imagery will then yield the desired information.

2) This technique is similar to (1) but it is based on false color, as obtained with the IR-color emulsion. This accentuates radiation in the near IR spectrum so as to make the sources more visible on the photograph.

3) The sensor collects black and white records in the three primary spectral regions associated with the normal-color visual process. The three multispectral images are then projected onto a screen by an additive color viewer so as to form a single, combined image as in (1). The analysis is now aided by an ability to adjust the extra dimensions of brightness and saturation for each of the primary hues. A fourth channel is often used to extend the spectral response of the system out to 0.9 μm. This, together with the gain in information achieved by the manipulation of the color separations, provides a greatly enhanced discrimination capability. The technique, known as multiband photography, can thus produce false color images which are roughly analogous to those obtained directly by method (2), but with a great deal of flexibility as to color composition.

4) More than three multispectral images are collected. The spectral records would then be scanned on an object basis to determine specific densities. Since the density of each resolvable element actually represents a photometric quantization, the multiple readings, in essence, comprise a target signature.

Multiband photography makes use of conventional aerial films rather than specially developed ones. Several manufacturers, including the Kodak Company, produce a wide variety of aerial films, and detailed descriptive data is readily available. The film characteristics of importance are: resolving power, speed, spectral sensitivity, and base type.

New films are continually being introduced, adding to the growing inventory of available aerial films. For example, Kodak Infrared Aerographic Film 2424, with an emulsion similar to 5424 but slightly slower, and on a 102-μm Estar base, has been made available within the past year. Several film types, not publicly listed by Kodak, have been used in manned space photography. Table 6-1 lists these new films; in most cases, the use of a standard emulsion on a different base has resulted in the change of the name of the film type.

A convenient aid for proper selection of films and filters is an aerial exposure computer, available from Eastman Kodak, since 1966; it is designed for use with Kodak aerial films and a few different Wratten filters. Factors such as exposure, altitude, focal length, and ground speed can be utilized to determine the image motion on film. Solar angle, camera altitude, film and filter types, haze condition, and exposure time can be used to ascertain the proper F-number that is required of the camera system.

6.2 FILM-BATCH SAMPLING

The photographic emulsion on its support of film, paper or glass, is an extremely delicate system and great vigilance is required in the manufacturing process to maintain the high degree of reproducibility from batch to batch that is found today in commercial films. In controlling manufacture and in the testing of the finished product, sensitometry is extensively used for obtaining precise figures for speed, contrast and fog. These figures, for the finished product, must fall within predetermined limits or the film is rejected.

TABLE 6-1

KODAK FILMS USED IN MANNED SPACE PHOTOGRAPHY THAT HAVE NOT BEEN PUBLICLY LISTED

FILM TYPE	THICKNESS*	FILM TYPE USING SIMILAR EMULSION
SO-168	64 µm	8442
SO-368	64 µm	2448
SO-246	102 µm	5424
SO-164	64 µm**	3400
SO-267	64 µm***	2405
2485	102 µm***	----

* All films listed use the Estar base

** The only difference between SO-164 and 3400 is the fast-drying backing used for SO-164.

*** This film is called Kodak Lunar Recording Film.

**** High-speed black and white film for lunar photography.

In spite of the excellent quality control utilized by the film manufacturers, variations will and do occur from one batch to the next. One means of compensating for these differences is to secure film in large batch quantities; then a sampling of this batch can be used to determine the sensitometric characteristics of the film, providing accurate values of the important emulsion properties for the entire lot. Sensitometeric tests can be performed on just a few pieces from the entire batch with confidence that all film cut from the batch will have similar properties.

The film-batch properties, determined before the mission from the sensitometric measurements, are then used to optimize the film developing and image copying functions.

In film development, the measurements allow for the construction of the characteristic curves which provide a convenient way of comparing different developer formulae for speed and contrast. In large-scale developing baths, sensitometric control strips can be used together with chemical analysis of the developer to determine the most effective and economical way of replenishing the bath in order to keep its chemical activity constant as more and more film is developed.

In the duplication and copying of negatives, it is often necessary to prepare duplicate negatives as well as negatives of a contrast differing from the original. A knowledge of the appropriate sensitometric values of a suitable range of materials enables this to be done without any guesswork and reduces wasted effort and material to a minimum. This includes deriving the correct new exposure time from the measured relationships between exposures and density levels.

6.3 ENVIRONMENTAL CONTROL

Since photographic film is a rather delicate medium for data recording, control of its environment in all aspects of its use, from manufacture through copying, is mandatory. Controlling the environment actually begins even before the emulsion is coated upon its support. Rigorous quality control procedures are implemented by the manufacturer to insure uniformity of film characteristics and prevent degradation of the film sensitivity. Concern must be maintained even after the film has left the factory, to insure that environmentally induced deterioration does not occur.

The effect of environmental conditions on film, and the specific areas where handling standards are required, are discussed in the subsequent paragraphs.

6.3.1 Environmental Effects on Film

Photographic emulsions are sensitive to both ultra-violet radiation and penetrating radiation from x-rays, gamma rays, and high-energy particles. The earth's atmosphere provides a measure of shielding from the ultra-violet radiation for conventional films. Beyond the atmosphere, extreme care is required to prevent stray light from entering camera systems because the ultra-violet energy level is considerably higher in this region.

Exposure of sensitized silver halide crystals occurs from alpha and beta particles. In spite of the fact that film is highly sensitive to these particles, it is easily protected by the thin metal that, in normal camera construction, is used in the fabrication of the film cassettes which hold the film.

X-rays and gamma rays are much more penetrating in outer space than in the atmosphere, and the shielding required for film must be as effective as that needed to protect the vehicle crew. All types of hard radiation produce similar results on film: loss of resolution, a decrease in film speed, loss of sensitivity, an increase in the fog level, and an increase in the granularity.

There have been reports that film, reconditioned in a normal atmosphere after being kept in a low-pressure environment, sustained no loss of dimensional stability; furthermore, no cracking or blistering of the emulsion was evident.

Polyester materials, developed in the past few years as a support material for the emulsion, have greatly improved film dimensional stability properties. Processing shrinkage is about one fifth as great for polyester-base film (0.02 percent) as for the older cellulose-triacetate-base film, which is about 0.10 percent. Relative humidity also has less effect on the former base material. Improved dimensional stability is an important requirement for almost all forms of imagery, not just those used in cartographic applications.

Tensile strength, tear resistance and break strength are also greater for the polyester base films than for the cellulose-triacetate bases. These qualities are becoming exceedingly more important, for both aircraft and spacecraft missions, when access to camera magazines is becoming more difficult, due to greater vehicle complexity, and the opportunity to photograph is so dependent on weather, launch opportunities and vehicle operational availability.

6.3.2 Control Areas

For effective and complete environmental control, suitable storage facilities must be provided both on the ground and in the taking vehicle. Sensitometric characteristics of film are most usually determined at 20° C. With most emulsions, a ± 20° C variation in ambient temperature will affect the photometric capability of the film-a lower temperature producing less image density with equal exposure energy. In unusual cases, where film must be used in a hard vacuum, unless moisture is returned to the film, permanent physical damage in the form of cracking or breaking will occur during handling.

The important areas where environmental control should be provided are:

- In transit from the manufacturer's plant to the site of mission operations;
- The warehouse where large batches of film are stored;
- The laboratories where film is cut to specific size and placed on roll spools;
- The aircraft film stockroom where material is stored just prior to the mission;
- In the vehicle before, during, and after the actual mission;
- The facilities that comprise both the data correlation system and the QC film development function.

6.4 SENSOR CONTROL

The control of the quality and quantity of data obtained from each sensor also enters into the generalized problem of data collection control. Two areas can be defined: on/off activation, and calibration.

6.4.1 Sensing Cycle Control

In aircraft installations and manned spacecraft, depending on the size of the vehicle and the accessibility of the sensor, activation will either be by direct operator control at the equipment station or by adjustment at a remote control panel. Unmanned spacecraft sensors must rely on ground-controlled telemetry signals for turn on/off. In each case, precise initiation and termination of the sensing cycle will have an impact on the amount of data collected, and loose regulation of this function will result in excessive amounts of unnecessary or redundant imagery and tape footage.

6.4.2 Equipment Calibration

Procedures and specifications are necessary for the checkout operation, and optical and electrical alignment of all equipments. Preflight and in-flight calibration procedures contribute substantially toward achieving the goal of providing high quality sensor data. Depending on the precision necessary for a particular mission, it may also be desirable to conduct calibration overflights of specially prepared test target-sites.

Classically, the major area of concern for imaging systems has been the sensor's ability to provide high-resolution, photogrammetrically accurate renditions. Current efforts with regard to calibration techniques relate to the uniformity of illumination in the sensor image plane. Conventional methods for axial and off-axis measurement of the relative transmittance of the sensor's optical system can provide basic calibration data. Ultimately, film sensor calibration will be accomplished by constructing an iso-density line trace of the image plane; this calibration data should be obtained under photometrically controlled conditions specially tailored for each different imaging sensor. If environmental stress is anticipated during data collection, in spite of precautions to assure a regulated environment, these conditions should be part of the calibration procedure.

Special laboratory facilities will be useful in gathering calibration data on all sensors. In addition, simulation techniques can be used to evaluate factors affecting operational performance, such as temperature, humidity, vibration, electrical biases, charge build-up, detector characteristics, etc. In some cases, this may lead to requirements for new or tighter controls on certain parameters; in others, the existing controls may be adequate but it may become necessary to record additional signals in order to eventually correct the data.

Some of the parameters of interest that should be explored in a Camera Calibration Laboratory are given in Table 6-2. Spectral photometric calibrations will be needed; these are not normally determined for cameras but, in an earth resources program, where spectral radiance is the key to information analysis, such measurements are vital.

Similar calibrations are required for each class of airborne sensor, and detailed measurements should be made on all instruments. Since the devices range from UV through radar wave-lengths and utilize entirely different sensing mechanisms, each type of system will require careful attention both in designing an effective test facility and in actually determining the calibration parameters, techniques and procedures.

In-flight calibration procedures, presently incorporated in the various sensors, utilize a variety of different calibrated reference sources. Table 6-3 is a listing of these calibrated sources and the sensors in which they are used in the Earth Resources Program.

6.5 SAMPLING CRITERIA

Signal outputs from prime sensor detectors are initially analog waveforms. If these are subsequently to be digitized, either in the air prior to recording or on the ground during playback, the conversions must be performed on a sample basis and must be properly timed. Similarly, the on-board NAV System must be sampled at appropriate rates.

TABLE 6-2 TYPICAL FUNCTIONS OF A CAMERA CALIBRATION LABORATORY

DETERMINATION OF LENS/ CAMERA CHARACTERISTICS	VARIABLES
A. Metrical Information	• Temperature
• Focal Length	- Gradients
• Field Distortion	• Wavelength
• Resolution	• Air Pressure
- OTF (3 Bar Target)	- Gradients
- MTS (Sine Wave)	• Mount
• Principal	• Vibration
• Plate Perpendicular	• f - stop
• Optic Axis	• Angle off Axis
• Film Flatness	
• Reseau	
B. Shutter/f - Stop	
• Efficiency/Photometry	
• Speed	
C. Spectral Photometry	
Filter/Lens Transmittance	
- On Axis	
- Off Axis	

TABLE 6-3 IN-FLIGHT CALIBRATED REFERENCE SOURCES

UTILIZED IN EARTH RESOURCES PROGRAM SENSORS

CALIBRATED REFERENCE SOURCE	SENSOR
Visible Source, 0.3 - 0.7 μ Temp.- controlled black body, 1-14 μ	RS-14 Dual Channel IR Line Scan Imager
Cooled thermoelectric reference, -40° C Internal wavelength source	IR Scanning Spectrometer
Conical graphite black body	IR Radiometer
Internal Cavity at 55° C	PRT-5 Radiation Thermometer
Argon noise temp.: 50° K/130° K	MR-62, MR-64 Microwave Radiometers
Argon noise temp.: 125° K and 450° K	Multifrequency Radiometer
12KHz signal	Single Polarized Scatterometer
12KHz signal	Dual Polarized Scatterometer, 13.3 GHz.
10KHz signal	Dual Polarized Scatterometer, 1.6GHz
1 KHz signal	400 MHz Scatterometer
Internal Go/No-Go Self Test	16.5 GHz SLAR

Since timing requirements are a function of vehicle motion and sensor characteristics, relationships must be examined for:

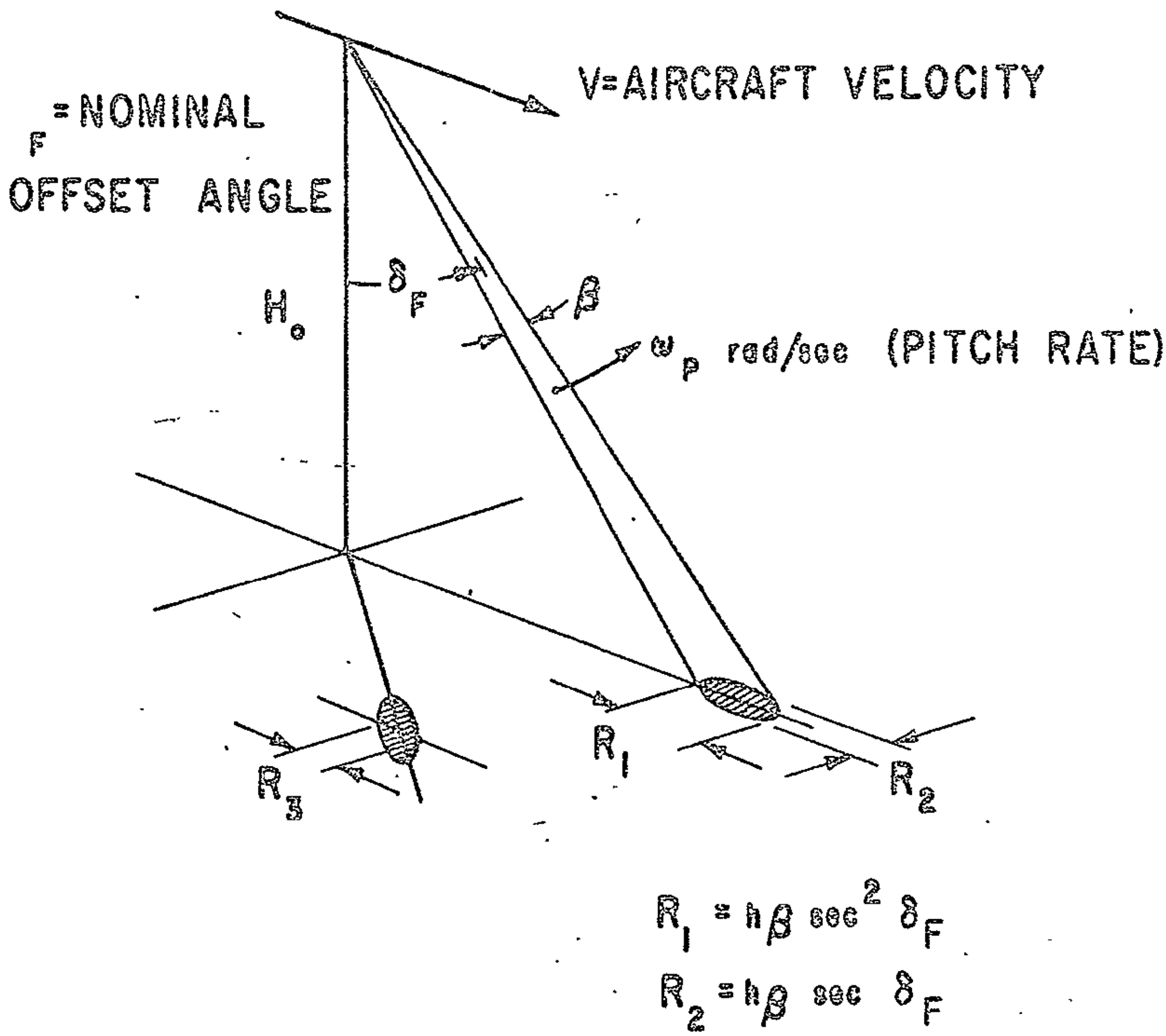
- Profile Thermometer
- Scanning Spectrometer
- Microwave Radiometer
- Radar Scatterometer
- SLAR
- Line Scanner
- Push-Broom Sensor
- TV Sensor
- NAV Data

The intent, here, is to summarize relationships and indicate nominal sampling rates based on the stated parameters of existing equipments and collection vehicles. In practice, the derived rates may have to be adjusted as more suitable values are chosen for key parameters such as effective beamwidth, signal integration time, or number of samples to be averaged for noise reduction. All such adjustments are straightforward.

6.5.1 Profile Thermometer

The generalized case for a profile thermometer is shown in Figure 6-1. If the sensor platform were perfectly stable, then R_1 could be taken as the ground distance equivalent to one data element and the necessary sampling rate would be V/R_1 elements per second.

However, the platform is not stable. If, for example, the aircraft were to drop in altitude and/or pitch upward, the sampling rate for contiguous ground "spots" would have to be increased proportionately



PROFILE THERMOMETER GEOMETRY

FIGURE 6-1.

Moreover, roll, yaw and velocity perturbations would also necessitate compensating adjustments. Furthermore, a yaw condition suggests that the dimension R_3 might be used instead of R_1 or that some mean value $R^* = \sqrt{R_1 \quad R_2}$ be adopted.

It is unnecessarily complicated, and of no real value, to attempt to maintain perfect contiguity between variable sized and shaped ground elements. A better approach is to use a fixed sample rate based on "worst case" conditions.

For the geometry shown in Figure 6-1, a maximum sampling rate is necessary for the case $\delta_F = 0$. Under that condition,

$$S = \frac{1}{\beta} \quad (V/H + \omega_\rho \quad) = \frac{(V/H)^*}{\beta} \qquad (6\text{-}1)$$

The anticipated V/H range for the NASA vehicles is about 0.02-0.2 rad/sec. Since attitude rates in normal flight can exceed 0.1 rad/sec, their effect on equivalent V/H can be significant. For the sake of assigning representative values to existing MSC sensor systems, assume $(V/H)^* = 0.3$ rad/sec. Then minimum sampling rates for the thermometer devices are as follows:

Sensor	β	S
Block Radiometer	2.5 mrad	120 samples/sec.
	7 mrad	43 samples/sec
PRT-5	35 mrad	9 samples/sec

If sample averaging is necessary for noise reduction, then the above rates should be multiplied by N - the number of averaged readings.

6.5.2 Scanning Spectrometer

This type of device has the same geometrical relationships as the profile thermometer but must sample n spectral bands per ground spot. For the Lockheed unit, $n = 90$, $\beta = 7$ milliradians so the sampling rate corresponding to $(V/H)^* = 0.3$ is

$$43 \; \frac{\text{spectra}}{\text{second}} \times 90 = 3870 \; \frac{\text{elements}}{\text{second}}$$

Since the equipment is limited to 6 spectra/second there will be gapping for $(V/H)^* > 0.042$ radians/second.

6.5.3 Microwave Radiometer

Figure 6-2 presents the collection geometry for a downward pointing radiometer. Unlike the thermometer case, this device integrates the received energy over an adjustable time interval, t_I. Consequently, the total area in view during t_I is that defined by R_1 and R_2 in the figure, and the effective ground cell is the shaded portion, with dimensions R_1^* and R_2.

Ideally, integration time should be matched to the sensor resolution and adjusted for look angle and equivalent V/H. If the unit were pointed forward by δ_F degrees, the desired relationship would be:

$$t_I = \frac{\beta \sec^2 \delta_F}{(V/H)^*} \tag{6-2}$$

In practice, however, t_I is set at some nominal constant. Hence, regardless of pointing angle, the ground dimension of interest is

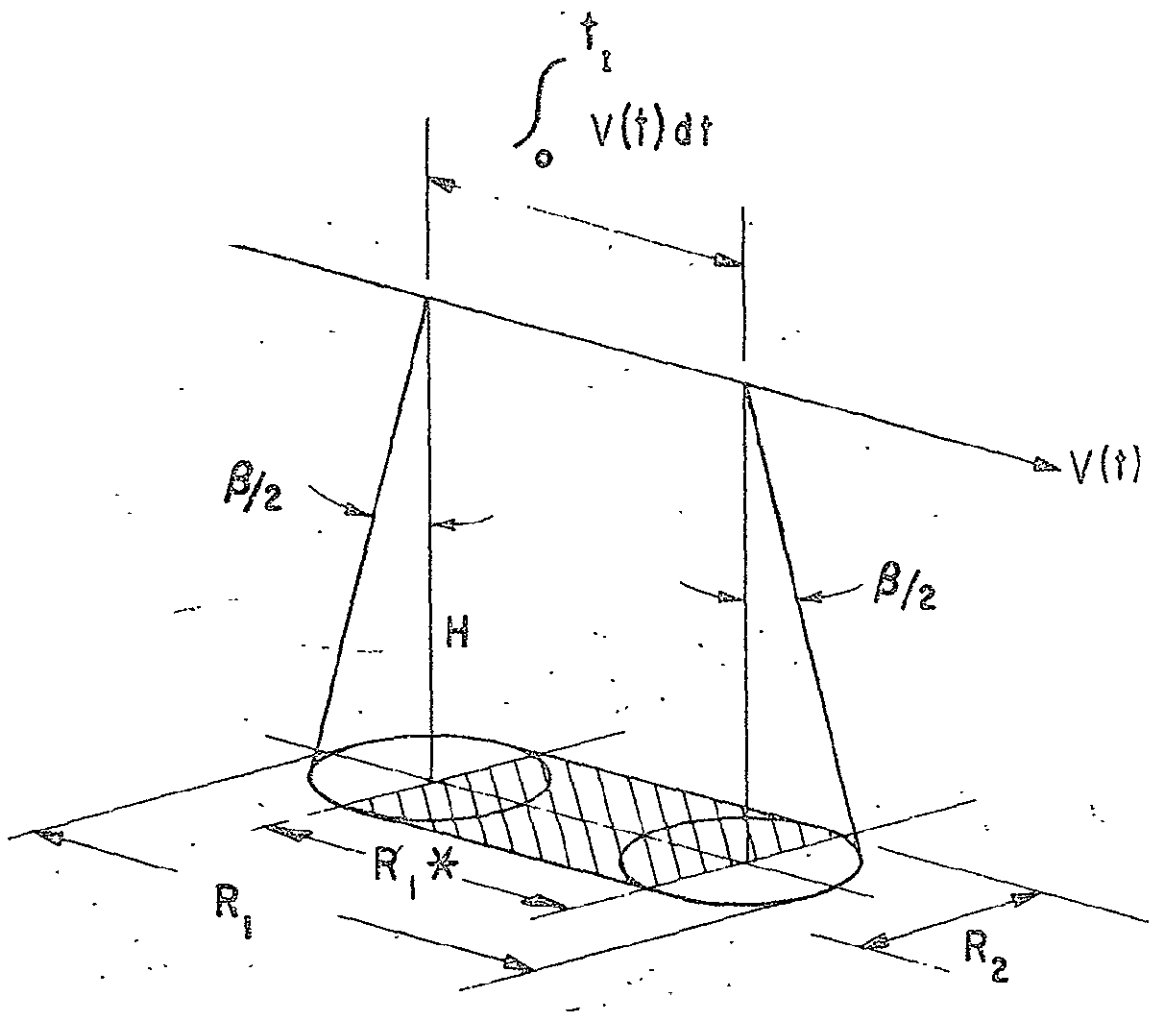
$$R_1^* = \int_0^{t_I} v(t)dt \cong Vt_I \tag{6-3}$$

and the corresponding sampling rate is

$$S = \frac{V}{R_1^*} = \frac{1}{t_I} \tag{6-4}$$

As before, the highest rates correspond to the case $\delta_F = 0$. Then, combining terms,

$$S = \frac{(V/H)^*}{\beta} \tag{6-5}$$



MICROWAVE RADIOMETER GEOMETRY

FIGURE 6-2.

For $(V/H)^* = 0.3$ rad/sec, the following relationships obtain:

Sensor System	β (deg.)	t_I nom. (sec.)	t_I calc. (sec)	S (samples/sec)
MR-62	2, 3	0.2	0.12, 0.17	8.6, 5.7
MR-64	1, 4	0.2	0.06, 0.23	17.2, 4.3
Space General	5, 6	1.0	0.29, 0.93	3.4, 1.1

6.5.4 Radar Scatterometer

Scatterometer geometry is illustrated in Figure 6-3. Antenna angles β_1 and β_2 define an instantaneous footprint with dimensions R_1 and R_2, as shown. However, scatter profiles are based on ground cells whose length in the track direction is determined by doppler frequency bin width.

At any angle, Γ_o, the corresponding doppler frequency is

$$f_o = \frac{2Vf_T}{c} \sin \Gamma_o \qquad (6\text{-}6)$$

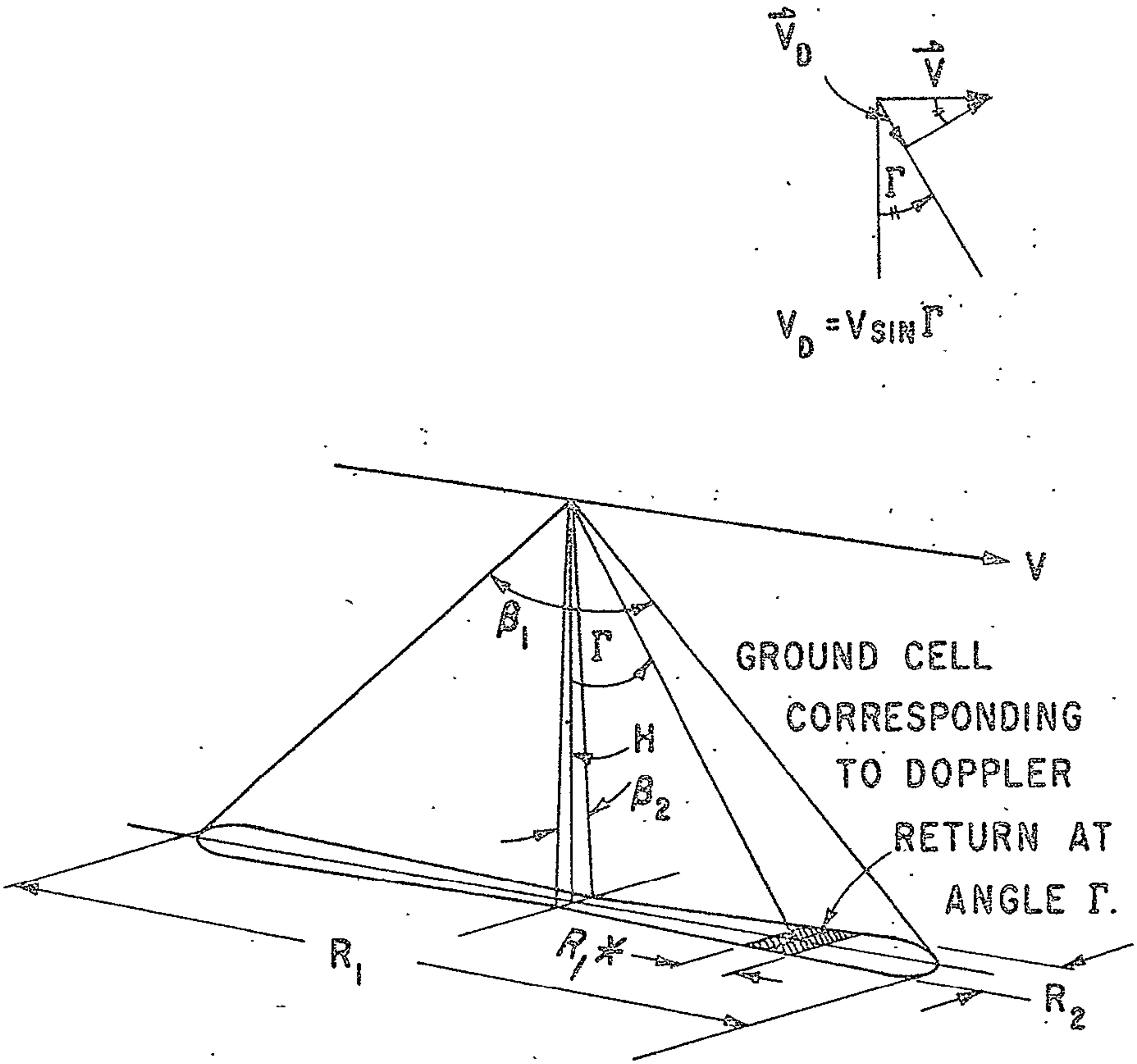
where

f_T = transmitter frequency
c = speed of light

Hence, a frequency range, Δf, centered on some value f_o, corresponds to an angular range, $\Delta \beta$, centered on an offset Γ_o. Then the dimension of interest, at an arbitrary look angle,

$$R_1{}^* = H \Delta \beta \sec^2 \Gamma \qquad (6\text{-}7)$$

can be re-stated in terms of a doppler center frequency and a filter bandwidth.



RADAR SCATTEROMETER GEOMETRY

FIGURE 6-3.

The ground cell width in the cross-track direction is determined by the antenna beamwidth, β_2. Ideally, all frequency bins are trimmed for the same size ground cell. Although there is no usable signal return from the vertical direction, it is convenient to use that limit case to define

$$R_1^* \equiv H\beta_2 \qquad (6\text{-}8)$$

as the resolution standard.

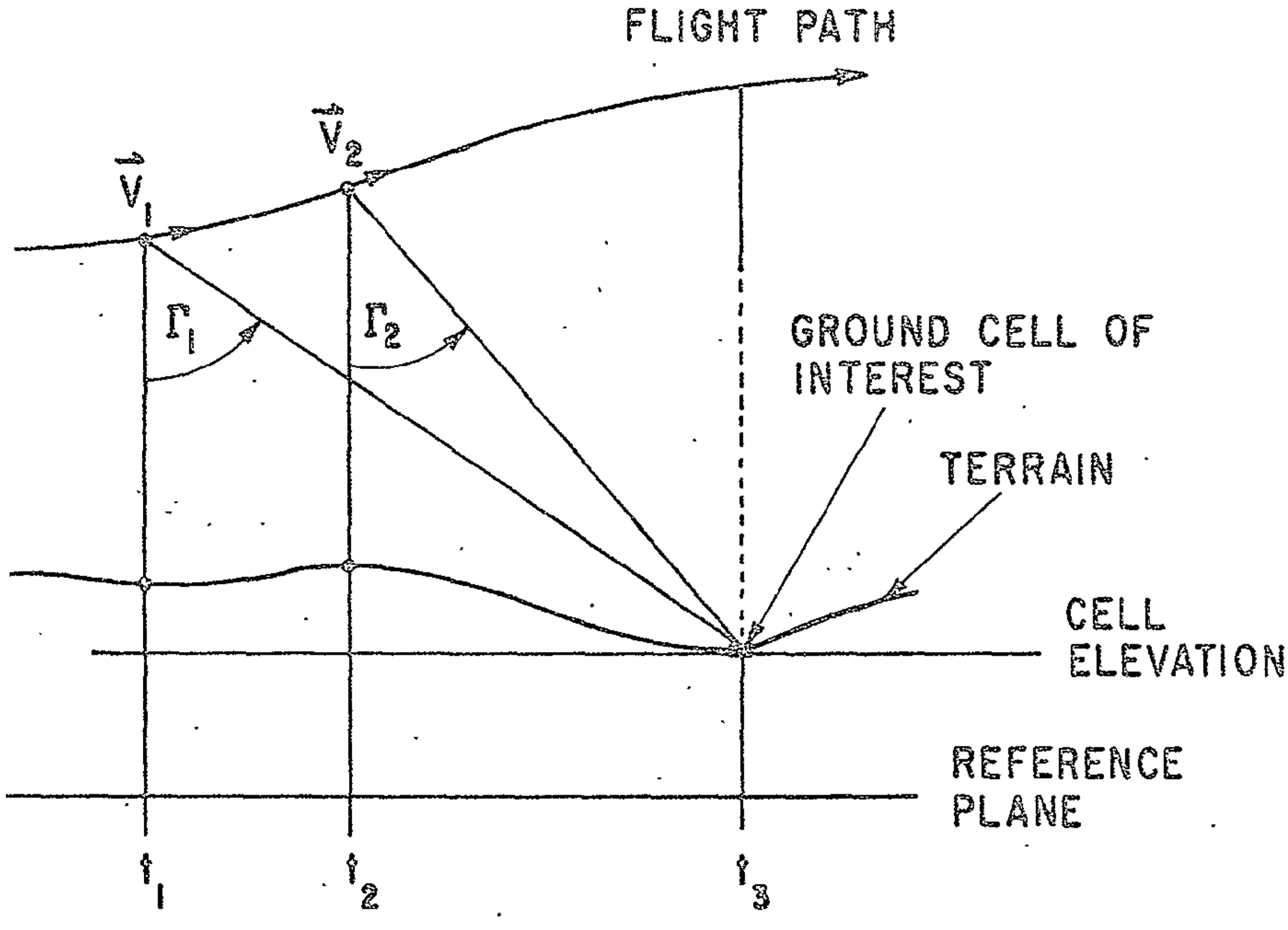
Then, for each filter, the nominal time interval between intercepting the centers of adjacent ground cells is

$$\Delta t = \frac{\beta_2}{(V/H)} \qquad (6\text{-}9)$$

Since the processing requirement is to construct scatter profiles for the ground cells, the situation is complicated by the time lapses and varying conditions which obtain as each frequency bin intercepts a particular cell. The problem is summarized in Figure 6-4, from which it is clear that the relevant variables include aircraft velocity vector (ground speed determines the doppler shift and both components define a climb angle which must be added to the nominal incidence angle, Γ), barometric altitude, radar altitude, pitch angle, pitch rate and collection time.

These difficulties are well understood and software programs have been available for several years to deal with them. For present purposes, it is of interest to note the cell interval times for the existing sensors, given a nominal (V/H) range of 0.02 to 0.2. Then:

Sensor	β_1	β_2	Δt
Ryan 13.3 GHz (2)	120°	3°	2.6 - 0.26 sec.
Ryan 1.6 GHz	120°	6°	5.2 - 0.52 sec.
Emerson 400 MHz	120°	9°	7.9 - 0.79 sec.



SCATTEROMETER GROUND CELL INTERCEPTS

FIGURE 6-4.

Clearly, the operational V/H should be kept as close to a constant as possible and, preferably, one at the high end of the range in order to minimize the cell interval.

The same Δt values, by definition, correspond to the intervals over which a series of data samples can be taken on any single ground cell, from any frequency bin. In the worst case, the 13.3 GHz system produces a doppler frequency range of about 10 KHz, so accurate signal analysis at the high end requires a digitization rate of at least 20,000 samples/second.

6.5.5 SLAR

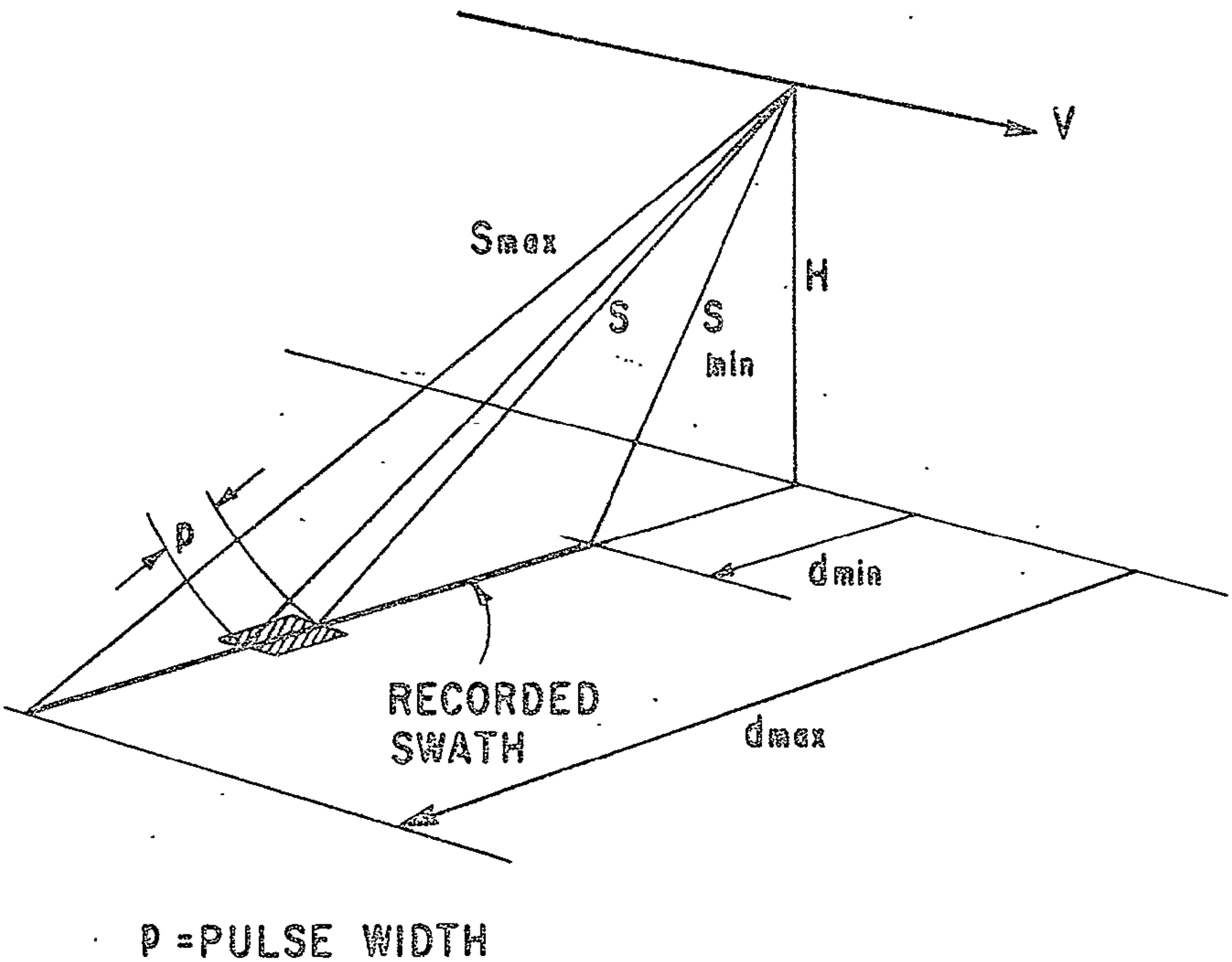
SLAR data is presently imaged on 5-inch film via a CRT Recorder in the airborne equipment. Figure 6-5 depicts the collection geometry. One could conceivably store the processed (unfocussed synthetic aperture) electrical signal in analog or digital form on magnetic tape but neither alternative is practical yet and the potential advantage is dubious.

For range resolution on the order of 100 feet, system pulse width would be about 100 nanoseconds. Consequently, for good reproduction, an analog recorder would require a bandwidth of at least 10 MHz and any sample - and - digitize scheme would have to operate at 20×10^6 elements/second.

Video recorders are available with 10 MHz bandwidths but their performance in an aircraft is questionable. Digitization could be accomplished by phased clocking of a set of A/D converters, each operating at a lower rate, but the technique is cumbersome, requires parallel channel recording (to reduce to reasonable bandwidths) and extensive, costly, modification of existing on-board and ground pre-processing systems. Therefore, the present film recording method is preferred.

6.5.6 Point Scanners

For clarification, define a "point scanner" as a remote sensing device with a narrow instantaneous field of view which is mechanically scanned over some larger coverage pattern. Two types of pattern must be considered



SLAR GEOMETRY

FIGURE 6-5.

and, in order to keep the distinction clear, the corresponding hardware systems will be termed:

- Line Scanners
- Arc Scanners

Figure 6-6 illustrates the two cases.

6.5.6.1 Line Scanner

As in the case of the profile devices, use the nadir "spot" to determine the conditions for contiguous data samples. Then the necessary scan rate is:

$$s = \frac{V/H}{\beta} \quad \text{scans/second} \tag{6-10}$$

In one scan there are

$$n = \frac{2\,\gamma_{max}}{\beta} \quad \text{elements} \tag{6-11}$$

Hence, the sampling rate is

$$S = \frac{2\,(V/H)\,\gamma_{max}}{\beta^2\,F_a} \quad \frac{\text{elements}}{\text{second}} \tag{6-12}$$

where

$$F_a = \frac{\text{Active scan time}}{\text{Total scan time}}$$

Ordinarily, angular rotation is constant; i.e..,

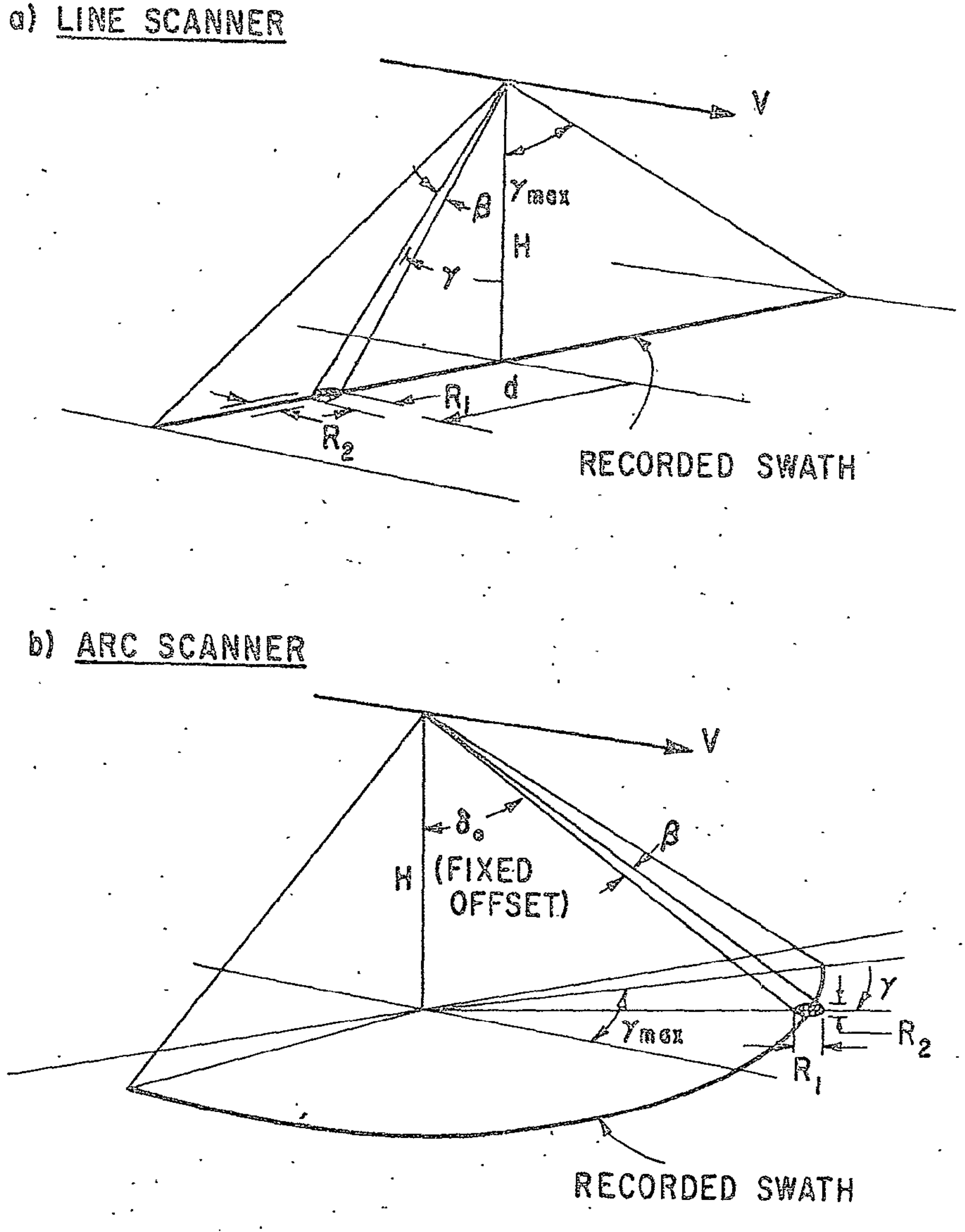
$$\gamma = Kt \tag{6-13}$$

This produces a non-linear spot travel, for

$$d = H \tan\left[\gamma + \omega\right] = H \tan\left[Kt + \omega(t)\right] \tag{6-14}$$

where

$$\omega = \omega(t) = \text{roll angle.}$$



POINT SCANNER GEOMETRIES

FIGURE 6-6.

ata can be recorded on film or on magnetic tape. CRT film recorders sually rectilinearize the scan line by using a tangent sweep function nd may or may not roll-compensate at the same time. The sensor may lso compensate for roll by mechanically overscanning and slipping sync s a function of instantaneous roll angle.

A similar rectilinearization could be performed prior to tape ecording if the analog signal from the sensor were first digitized. The cheme entails an automatic adjustment of the time interval between samles so that successive measurements are at equal ground displacements.

$$\Delta d = H \beta \qquad (6\text{-}15)$$

As with the CRT recorder, dynamic roll correction should be dded. For an instantaneous roll angle, ωi, the required control function s

$$d = H \sec^2 \left[Kt + \omega i \right] \qquad (6\text{-}16)$$

Then the sample interval is

$$\frac{1}{s} = \frac{d}{\Delta d} = \frac{1}{\beta} \sec^2 \left[Kt + \omega i \right] \text{ seconds} \qquad (6\text{-}17)$$

Note that if β is fixed the ground intercept "spot" varies in the scan direction as $H \beta \sec^2 \gamma$. Hence, equally spaced samples involve increasing amounts of overlap and more recorded elements per scan.

With this approach,

$$n^* = \frac{2 \tan \gamma \max}{\beta} > n \text{ elements} \qquad (6\text{-}18)$$

Line scanners of current interest have the following charateristics:

ensor	(V/H) max	β	s	γmax	n	n*
conofax IV	0.6	2 mrad	300 scans/sec.	±60°	1047	1732
		3 mrad	200 "		698	1155
-14	0.2	1 mrad	200 "	±40°	1400	1678

Sensor	(V/H) max	β	s	γmax.	n	n*
RS-14		3 mrad	67 $\frac{\text{scans}}{\text{sec.}}$		467	559
Bendix (24-chan.)	0.2	2 mrad	600 "	±40°	700	839

For multispectral scanners, each "element" contains m bands. If the Bendix device were to sample all channels in series and if there were no dead time (Fa = 1), then

$$S = 600 \times 700 \times 24 \approx 10^7 \quad \text{samples/second}$$

This is a prohibitive rate and so the channels must be handled in parallel or in some parallel/series manner. For complete paralleling, S is 42,000 elements/second. Therefore, the given recorder bandwidth of 240 KC is adequate provided Fa $\geqslant$ 0.88.

6.5.6.2 Arc Scanner

An arc scanner offers the attraction of a constant size ground spot but requires a two-dimensional geometric correction if the data is to be ordered in some rectangular coordinate system. Also, if the longitudinal and lateral FOVs, β_1 and β_2, are equal the spot, while of fixed shape, will rotate as the scan develops. With respect to the sampling problem:

$$s = \frac{V}{R_1} = \frac{V/H}{\beta_1} \cos^2 \delta_0 \quad \frac{\text{scans}}{\text{second}} \tag{6-19}$$

$$n = \frac{(2H \tan \delta_0) \quad \gamma_{max}}{R_2} = \frac{2\,\gamma_{max}}{\beta_2} \sin \delta_0 \quad \frac{\text{elements}}{\text{scan}} \tag{6-20}$$

$$S = \frac{2\,(V/H)\,\gamma_{max}}{\beta_1 \;\beta_2 \;Fa} \sin \delta_0 \quad \cos^2 \delta_0 \quad \frac{\text{elements}}{\text{second}} \tag{6-21}$$

The swath width viewed is

$$W = 2\,H \tan \delta_0 \sin \gamma_{max}. \tag{6-22}$$

If such a system is to provide coverage comparable to a line scanner, then

$$\gamma_{max_{\text{ARC SCAN}}} \longrightarrow \pi/2$$

$$\delta_0 \longrightarrow \gamma_{max_{\text{LINE SCAN}}}$$

Rectilinearization is possible either with a CRT recorder or with digital processing; the latter requires a high speed random access store (e.g., core) for at least $\frac{\tan \delta_0}{\beta_1}$ lines of data.

6.5.6.3 Sampling Error

Waveform sampling is performed, ideally, via precisely positioned delta functions of zero width. In practice, it is sufficient that the sample pulse have a much shorter time duration and position jitter than the most rapid waveform fluctuation of interest. Modern sampling networks use apertures on the order of 50 - 100 nanoseconds and clearly satisfy the timing requirements for most applications. However, high speed/high resolution point scanners introduce the possibility of operating at data intervals which begin to approach sub-microsecond time ranges. The question is, where does this start to seriously degrade measurement accuracy?

Consider the case shown in Figure 6-7a. For nominal sample times t_A, t_B, t_C the desired readings are e_A, e_B, e_C. A sample and hold network with a gated aperture of Δt seconds could behave in several ways, depending on the design of its charging circuit. The variations can be bounded by examining the ideal performance of three hypothetical types:

Type	Measurements		
Peak detector	e_2	e_B	e_5
Perfect follower	e_2	e_4	e_6
Mean-value integrator	e_A	$\frac{1}{2}\left(e_B + \frac{e_3 + e_4}{2}\right)$	e_c

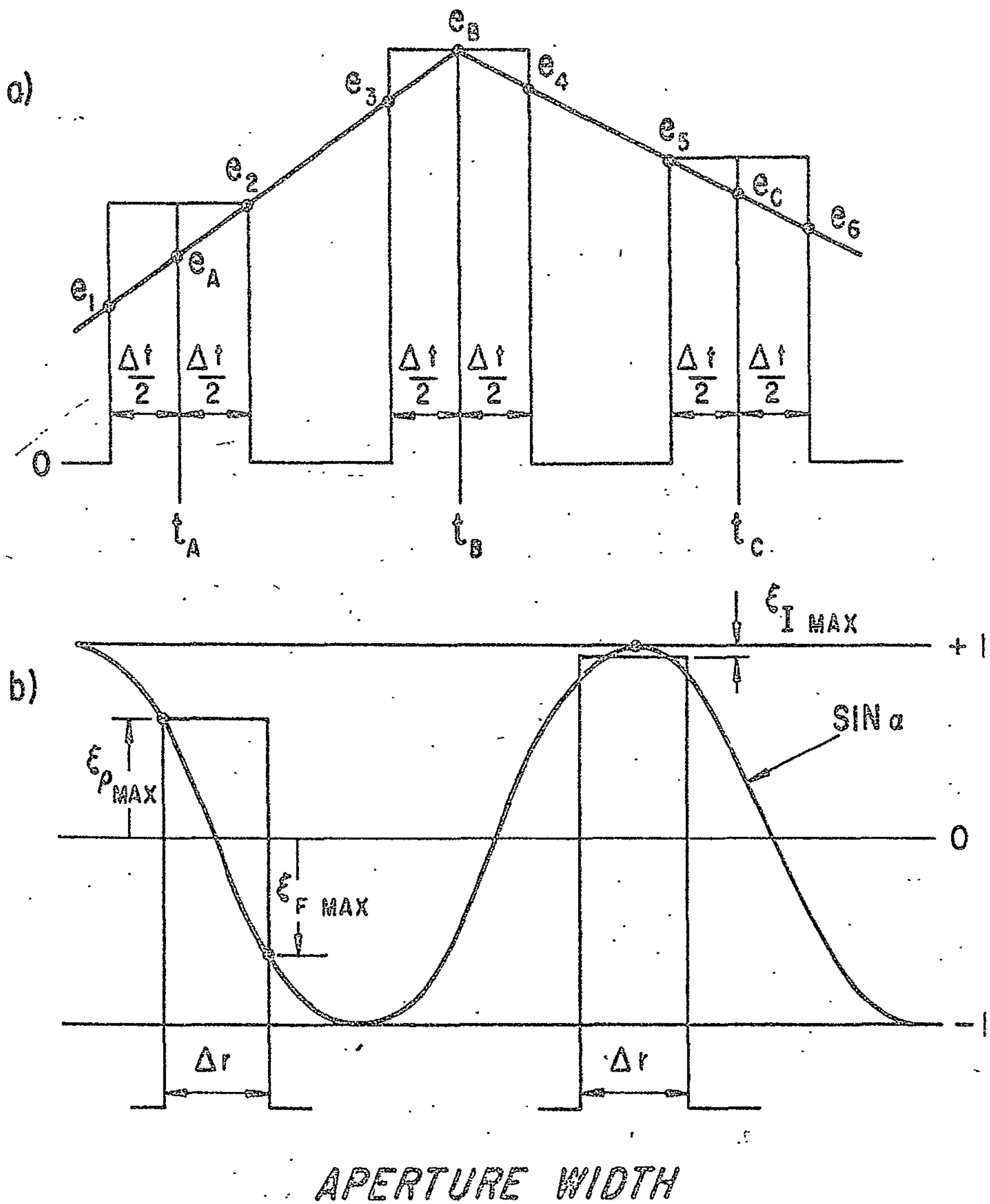

a)
e_B
e_1
e_2
e_3
e_4
e_5
e_6
e_A
e_C
$\frac{\Delta t}{2}$
O
t_A
t_B
t_C
b)
$\xi_{I\,MAX}$
+1
SIN α
$\xi_{\rho_{MAX}}$
O
$\xi_{F\,MAX}$
-1
Δr
APERTURE WIDTH

FIGURE 6-7.

It follows that the first two types will be most in error when the sampled waveform has a maximum monotonically increasing or decreasing slope over the sample interval, Δt, but that the integrator error will be largest when the signal slope changes sign during Δt.

Then the worst case errors arise under the timing conditions shown in part (b) of the figure. The waveform is a sinusoid of the highest frequency component that can appear.

The peak detector and the follower would have identical maximum amplitudes, possibly differing in sign, and of value:

$$\mathcal{E}_{p\ max} = \mathcal{E}_{F\ max} = \sin \frac{\Delta r}{2} \tag{6-23}$$

The maximum integrator would be:

$$\mathcal{E}_{I\ max} = 1 \frac{-2}{\Delta r} \int_{\frac{\pi - \Delta r}{2}}^{\pi/2} \sin \alpha \ d\alpha$$

$$= 1 \frac{-2}{\Delta r} \sin \frac{\Delta r}{2} \tag{6-24}$$

For $X << 1$,

$$\sin X \approx X - \frac{X^3}{3!}$$

Also, for Δt in seconds and a minimum period $T = 1/f_{max}$,

$$\Delta r = \frac{2\pi\Delta t}{T} \quad \text{radians} \tag{6-25}$$

Then the above equations reduce to:

$$\mathcal{E}_p \max = \mathcal{E}_F \max \approx \pi \left(\frac{\Delta t}{T}\right) - \frac{\pi^3}{6} \left(\frac{\Delta t}{T}\right)^3 \qquad (6\text{-}26)$$

$$\mathcal{E}_I \max \approx \frac{\pi^2}{6} \left(\frac{\Delta t}{T}\right)^2 \qquad (6\text{-}27)$$

Quantitatively, the error fall-off is:

$\Delta t/T$	$\mathcal{E}_I$ max (%)	$\mathcal{E}_p$ max, $\mathcal{E}_F$max (%)
1/10	1.64	30.9
1/100	0.016	3.14
1/1000	0.00016	0.31
1/10,000	1.6×10^{-6}	0.03

For profile sensors, T is on the order of seconds, so $\Delta t/T \approx 10^{-7}$ and errors due to sample aperture are completely negligible. However, point scanners operating at rates of upwards of 200,000 elements per second per spectral channel have maximum frequencies of 100 KHz and higher, or a T of less than 10 microseconds. Then $\Delta t/T$ can attain values of 1/100 or larger, and instrument errors can become appreciable.

A tentative conclusion to be drawn is that high speed point scanners should interface with matched sampling devices which:

1) have as short a sample interval, Δt, as is practical;

2) are designed to act essentially as mean value integrators over that interval.

The second criterion is generally met, approximately, because physical devices use holding capacitors which are charged through some small, but finite, resistance. Furthermore, it is possible to design integrated circuit A/D converters to sample at rates as high as 20-100 megasamples/second, with encoding in the range of 5-10 bits/sample. However, at those speeds and accuracies, the required aperture times are on the order of 1.0 - 0.2 nanoseconds. Clearly, the corresponding time base problems now become formidable.

If the A/D conversion speed is compatible, the sampler may be permitted to track the signal until commanded to rapidly disconnect and hold. Then "aperture time" signifies the switching interval and sub-nanosecond transitions are feasible. Note that the device now operates more in the manner of a "perfect follower". Hence, even if the disconnect were perfectly abrupt (which, of course, it is not), a time base jitter of $\pm \Delta t/2$ would produce the same $\mathcal{E}_F$ max errors as listed earlier in the derived table.

But <u>many</u> factors are involved in maintaining high-speed, precise accuracy: power supply noise, ground noise and stray signals can modulate the sampling process in time and/or amplitude; the switch drive signal can couple into the holding circuit and contaminate the data voltage level; propagation delays become significant; circuits must operate in the non-saturating region to drive low load impedances with fast response, so dissipations increase; since packaging must be kept compact, heat removal becomes more of a problem; logic and clock signals must have rise/fall times on the order of 1 nanosecond or less, so required circuit bandwidths can range up to 500 MHz; stray reactances can significantly distort waveforms and so the layout topology becomes an essential part of the design. These are only a few of the items to be considered. In general, the overall device must satisfactorily meet a large number of diverse requirements that arise in electrical, mechanical and packaging design.

The development of such a unit is not a task to be undertaken lightly. A preferable approach is, first, to analyze the devices now used in the Earth Resources program with regard to their suitability for sampling high speed sensor data, then consider parallel channel operation and/or the digitization of a reduced-speed analog playback. If the results are unsatisfactory, inquire about existing devices before pursuing a new development.

6.5.7 Push Broom Scanner

An ideal linear array of n solid-state detectors would have a sample rate,

$$S = \frac{n\,(V/H)}{\beta} \quad \frac{\text{elements}}{\text{second}} \tag{6-28}$$

Realizable systems would use a set of smaller arrays which would be scanned out in M parallel groups. Then the per-channel rate would be,

$$S = \frac{n\,(V/H)}{M\beta} \quad \frac{\text{elements}}{\text{second}} \tag{6-29}$$

6.5.8 TV Scanner

A television-type scanner has equivalent vertical and horizontal resolutions (TV lines per dimension) of:

$$R_V = KU_V L \tag{6-30}$$

$$R_H = \frac{2BW\,t_F U_h}{L} \tag{6-31}$$

where

K	=	Kell factor $\approx$ 0.75
U_V	=	Vertical unblanking factor
L	=	Total scan lines per frame
BW	=	Video bandwidth
t_F	=	Frame interval
U_h	=	Horizontal unblanking factor

If the picture dimension correspond to a horizontal: vertical aspect ratio, a, it is desirable to maintain equal equivalent resolutions by imposing the requirement

$$R_h = aR_v \tag{6-32}$$

Combining terms,

$$BW = \frac{1}{2} \quad \frac{KU_v L^2 a}{t_F U_h} \tag{6-33}$$

Two typical systems compare as follows:

	Commercial TV	RBV
U_v	0.935	1
L	525	4000 - 6000
a	4/3	1
t_F	1/30 sec.	4.8 sec.
U_h	0.83	0.9
BW	4.65 MHz	1.39 - 3.13 MHz

Real-time sampling of RBV data would, therefore, entail rates of about 2.8-6.3 million elements per second, minimum. In order to match the transmission channel capacity of 4 MHz, this would be further increased to 8×10^6 elements per second. This is a prohibitive rate with today's devices, but it can be reduced to manageable values by playing back an analog tape recording at slower than real time speed.

For a speed reduction of M times, sample rate is

$$S = \frac{8 \times 10^6}{M} \quad \frac{\text{elements}}{\text{second}} \tag{6-34}$$

The sampling should be resynchronized at the beginning of each scan line of data.

6.5.9 NAV Data

Sampling criteria for NAV data are determined by the maximum perturbation rates of the vehicle. Three classes of vehicle motion must be examined to assure that worst case conditions are satisfied. It is assumed that all NAV data will be monitored at the same rate, but data for each class could be collected independently if desired.

The categories are:

- Attitude............Heading, Pitch, Roll, Drift
- Ground Speed.......Velocity, Latitude, Longitude
- Altitude............Radar (or Laser) Altimeter

Wind gusts can cause abrupt disturbances in any direction but, for sizing purposes, assume that the maximum slew rate for each parameter represents the maximum slope on a full amplitude sinusoidal excursion.

Then the highest frequency encountered is:

$$f_{max} = \frac{r}{2\pi A} \quad (6\text{-}35)$$

where

r	=	maximum rate of change	(units/sec)
A	=	peak excursion amplitude	(units)

As always, the critical sampling rate is $2f_{max}$. The worst case for the three categories arises in attitude motions, where the most extreme values are

r = 24 degrees/sec
A = 15 degrees

This is a limit case. It is virtually inconveivable that such drastic motions would be encountered in actual flight. Nonetheless, the corresponding sampling rate is only 0.5 samples/second. Thus, it would appear that vehicle motions can be monitored at quite low rates. It should not be construed that this would lead to a satisfactory system design.

The problem is that NAV readings are necessary to compensate for the taking conditions of the prime sensor data. Therefore, accurate values must be available at rates commensurate with sensor timing. Consequently, if NAV data is sampled at extremely low rates then intermediate values must be calculated during ground processing. Much of that can be avoided, and all of it simplified, if NAV is read at a higher rate.

Specifically, it is desirable to reduce the computation of intersample values to a linear interpolation based on time. For a sinusoid, the maximum interpolation error occurs when consecutive samples exactly straddle $\pi/2$ radians. This is true for all values of sample spacing. Then

$$\% \; \mathcal{E}_{max} = 100 \left[1 - \cos \frac{\pi f}{S^*} \right] \tag{6-36}$$

where

f	=	excursion frequency	(Hz)
S^*	=	actual data sampling rate	(samples/second)

For the limit f_{max} of about 1/4 Hz and the current sampling rate of 40 per second, the worst-case interpolation error is on the order of 0.02%.

6.6 MISSION PARAMETERS

There are three major areas in which mission parameters must be carefully controlled in order not to degrade the end-to-end performance: NAV system updating, mission altitude and V/H limits, and the development of well-coordinated plans. Each of these areas of concern may be considered an integral part of the general problem of data collection control.

Navigational data should be subjected to certain specific tests in the preprocessing function to assure the validity of the data and to evaluate the operation of the aircraft NAV equipment. Section 7.3.5, "NAV Data Screening", discusses in detail the types of tests required as well as the need for them. However, even before the preprocessing function, the NAV data collected should be brought under control by updating the on-board NAV system. This is done by referencing fixed ground check points. At planned intervals, check point fixes - either by radio telemetry, optical beacon or sighting of precisely known landmarks - should be made to reset the position system in order to compensate for accumulated gyro drift errors.

The problem of altitude limits enters into mission planning when one considers the degree of registration accuracy desired in the system products. Figure 4-3 showed the relationship between ground registration and the corresponding angular accuracy requirements at various aircraft altitudes. It can be seen that high altitude flights will require extremely accurate knowledge of vehicle attitude, even for the attainment of moderate ground registrations. As an example, a 100 foot ground accuracy requirement implies a vehicle taking accuracy of ±7 arc minutes at 50,000 feet. The requirement decreases to a very coarse value of more than 5 degrees at an altitude of 1,000 feet. Hence, the desired ground accuracy and the attainable equipment performance impose a ceiling on collection altitude. Excessive V/H directly degrades sensor performance in a number of well-known ways. Since the NASA aircraft are currently limited to a V/H range of 0.02 to 0.2, most sensors will be unaffected, However, as discussed earlier, the scanning spectrometer will gap for $V/H > 0.042$, and this must be taken into account in the collection flight profile.

Collection flights must be planned, as they currently are, with regard to both coverage and timing. Adjacent flight legs must be spaced so as to provide the degree of overlapping coverage desired, no more and no less; and the timing must be appropriate for proper coordination with ground teams and/or other vehicles, and for the desired taking conditions (crop maturity, sun angle, etc.)

SECTION 7

PREPROCESSING

FOREWORD

This section describes the raw data handling, screening and initial conditioning operations which will be performed, as standard practice, on all mission inputs. Figure 7-1 indicates the functional sub-tasks involved and the normal system flow which links them.

From Figure i, "System Overview", it was apparent that there are two major processing chains that carry through the entire Data Correlation System; viz., one concerned with film handling and one designed to accommodate data recorded on magnetic tape. It can be seen from the Preprocessing diagram (Figure 7-1) that, even this early in the flow, those major paths are not simple and isolated but, rather, they:

- Must cycle through identical functions several times (e.g., QC film development or Tape decommutation readouts);
- Can branch into distinct sub-paths within a major flow;
- Can include data conversions (tape/film) that lead to interacting flows;
- Cannot be entirely automated; i.e., many functions, particularly in film handling, require the direct physical intervention of a human operator (unless implemented in an inordinately complicated manner, such as with moving belts).

Subsequent portions of this section will describe an idealized flow through the identified functional blocks. For simplicity, let it be tacitly assumed that, in the fully-evolved system under discussion:

1) All equipments are tied to the Central Computer in some optimum fashion and properly send status signals and data identification codes as required;

2) On-line CRT terminals are available throughout the system, providing two-way communication with the Management System wherever needed;

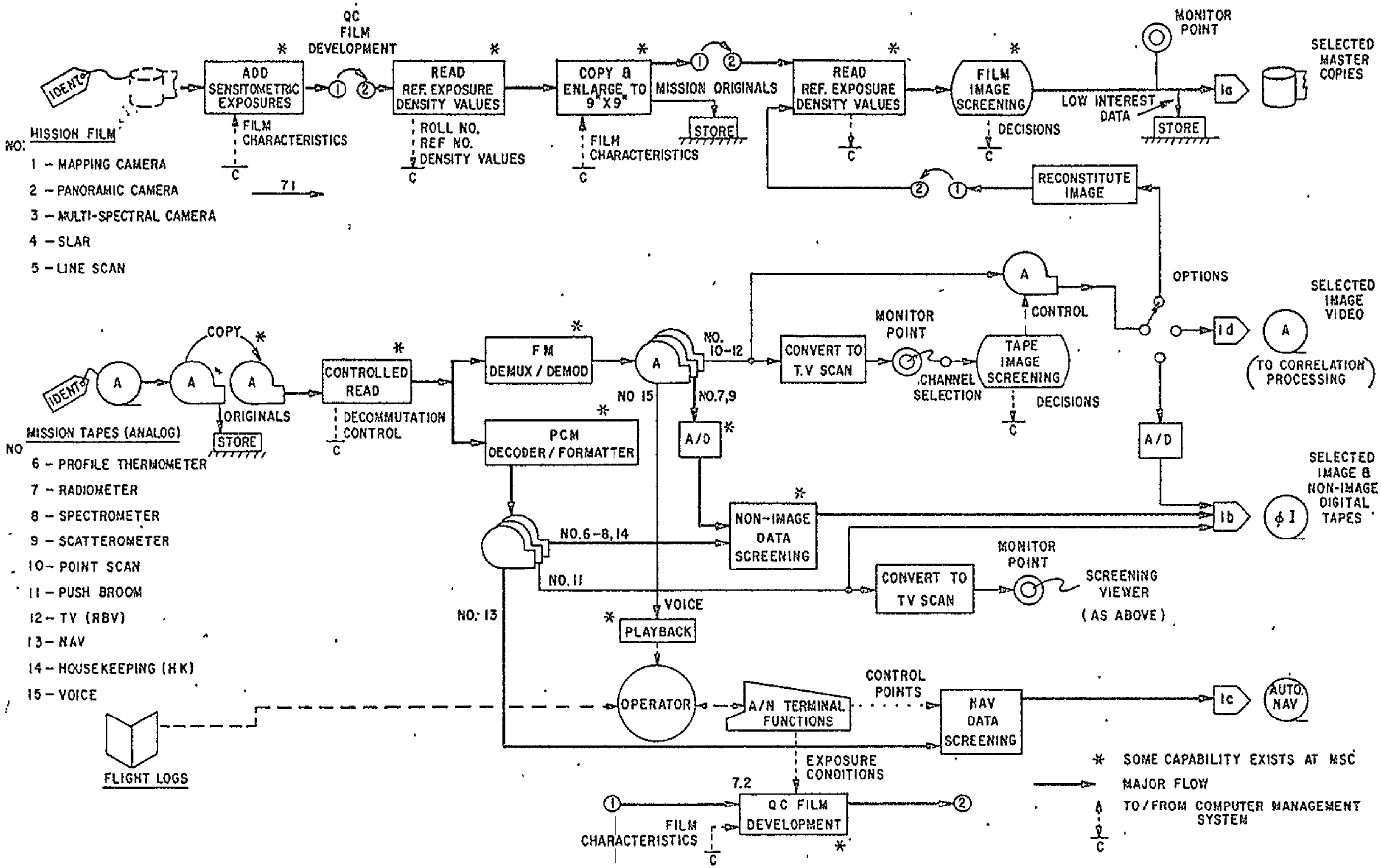
3) Functions essentially identical to ones currently performed at MSC will not differ in any fundamental way, except as noted, and therefore need not be described in specific detail here.

These same assumptions will be held throughout the remaining sections of this report as well.

SECTION 7 CONTENTS

SECTION 7 CONTENTS
(Continued)

ILLUSTRATIONS PAGE



PREPROCESSING FUNCTIONS

FIGURE 7-1.

7.1 FILM HANDLING AND SCREENING

All original mission film receives sensitometric exposures as the first step in the film preprocessing flow. These controlled exposures, made through a standard step wedge, are later used for primary sensitometric tests of black-and-white and color emulsion characteristics in order to standardize film developing. Computer-derived signals control the exposures in response to the known film batch characteristics.

After photo lab developing, the step wedge density values are read out by the densitometer and relayed to the computer. Identification to the computer is also made of other needed information such as mission number, film roll number, etc.

The copy-enlarge function provides all the photo copies needed for subsequent processing, allowing storage of the mission originals. Information on film characteristics is fed from the computer to control the copy-exposure equipment settings for: exposure time, f-number, magnification, etc. Standardized formats result from this function with 9 x 9-inch size for all mission imagery except the boresight photography, which is copied one-to-one on 70 mm film. No attempt is made here to bring about conformity of scale between the various films; only the format size is standardized.

Following the copy function, the standardized 9-inch and 70 mm imagery is developed in the QC photo lab and channeled to a second densitometer station whose function is to read out the step wedge density values for the master copies. These values, transferred to computer storage, assist in maintaining accurate control of the quality of standard copies used in all subsequent film processing.

Main-flow processing then continues with the screening function. Here, the first detailed processing decisions are made by the viewing specialist. By means of a keyboard he enters frame by frame (or per time slice) instructions which establish imagery routing for all subsequent film handling. Frame identifications can be read automatically or entered manually.

7.2 QC FILM DEVELOPMENT

In the preprocessing section, as well as in other parts of the automatic data correlation system, photographic data must be processed through a

cycle labeled "QC film development". By "film development" is meant only latent image recovery; copying, enlarging and printing are part of the preprocessing section but lie outside of this definition. This important function is vital to assure the production of quality-controlled photographic imagery. Research, over the years, has proven conclusively that resolution, image density, dimensional stability, edge gradients, etc., become random variables in uncontrolled film developing environments.

Based on the need for controls before, during and after the photographic mission, on the difficulties associated with raw materials, and on the limited capability of the existing photographic control program, there is a need for a thorough study of this problem. The beginnings of a solution are now underway at MSC and it appears that progress is being made in the Photo Technology Laboratory to provide the precision development necessary to produce high order metric-type imagery.

There is also a flow problem to be considered. It is apparent from the system diagrams (Figures i, 7-1, 8-1, 9-1) that film development cycles are necessary at dispersed points in several flow paths. In the Pilot System, all of these activities can be performed in one film development laboratory by sequencing them in time. But a production processing system entails a complex, high-volume traffic flow which could easily overload a single facility. So, eventually, an analysis will have to be performed to determine whether the operational system should have one large film development facility or several, physically separate, smaller ones.

The following paragraphs present some cursory remarks on the uniqueness of film for data recording and discuss how a few of the key factors that enter into film development affect the quality of the photography to the extent that precise control is necessary if good output products are to be obtained.

7.2.1 Advantages and Limitations of Film

The use of film as a data recording medium is prompted by its unique properties, among which are the ability to record information bits in great capacity and with excellent spatial precision. Furthermore, each recorded terrain reflectance anomaly is precisely located within a large collection area at a specific instant of time, i.e., the instant of exposure.

These properties make photographic film an almost ideal recording medium. However, to achieve state-of-the-art performance with film, careful attention must be paid to collecting the data within the operational limitations of the sensor, and accurate control must be exercised over the process that renders the latent image visible.

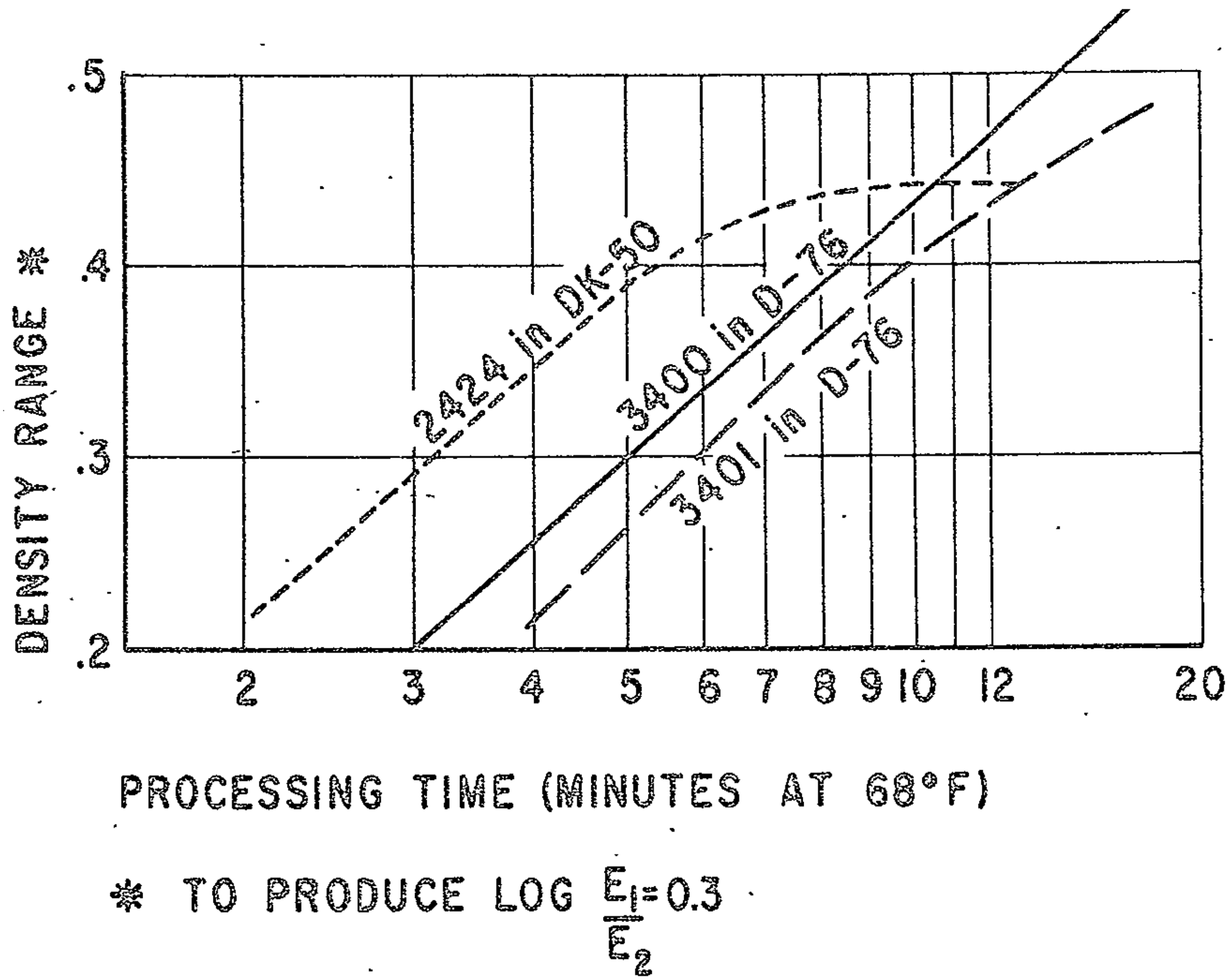
The need for recovery of the latent image is also a unique property of this recording medium. The sensitivity of the silver halide detector is a function of the development process, with an amplification process taking place during a chemical reaction that is known as either direct or physical development. Whichever reaction technique is employed, liquid is used to facilitate uniform wetting of the emulsion. In most instances, the film is placed into a bath of one form or another, although variations, such as diffusion transfer processing, have been developed in recent years. Very recent research has actually eliminated the need for a liquid in the chemical reaction. This "dry silver" technique utilizes high temperature to bring out the latent image; however, the performance characteristics are limited.

In an attempt to get away from the necessity of using "wet processes", the photographic recording science has brought forth a number of novel image-forming systems. Some of these, such as diazo, photo co-polymers and electrographics, are not based on silver salts; they offer the advantage of not requiring silver, a critical element. These forms of recording media may be useful, at a future date, in the Earth Resources program but they will not be considered here. The required Q.C. photo development, included in the preprocessing section and elsewhere, employs conventional liquid bath processing of photographic sensor film, both color and black and white.

7.2.2 Development Time

To insure that the image density is truly representative of the radiated energy incident on the film, the development time must be precisely controlled. Figure 7-2 shows the dependence of differential density on development time. From these curves, the need for closely controlled timing of the latent imagery recovery process can be established. For example, an error of 15 seconds, for a solution temperature of 68°F, can cause an error of .02 in the differential density when the incident energy range is 2 to 1. If this error is examined, in terms of a continuous immersion type process, the following tolerances can be established. The processing time is given by

$$T = \frac{L}{V}, \text{ minutes} \tag{7-1}$$



TIME VS. DENSITY

FIGURE 7-2.

where,

V = the throughput rate, in feet per minute (fpm)

L = the immersion path length, in feet.

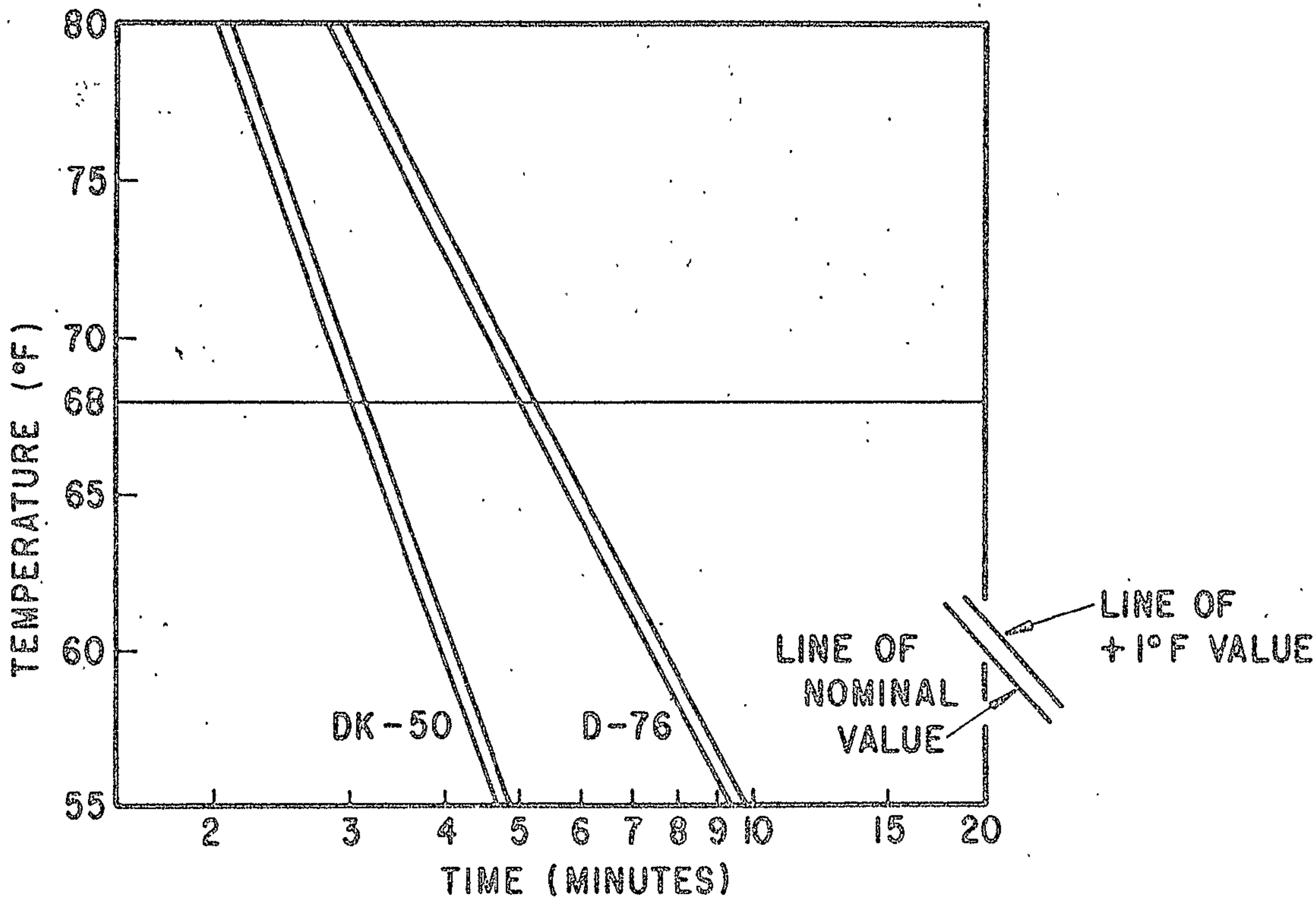
Since the velocity, V, in many machines is subject to line voltage variations, a 5 percent error in V is quite usual. The value of L subject to manual variance, is often difficult to adjust. For typical conditions of V equal to 14.25 fpm and L equal to 45 feet, T is found to be 2 minutes and 45 seconds as compared with the required time of 3 minutes. This results in an error of 5.8 inches or a tolerance of 1.1 percent.

The shape of the curves in Figure 7-2 is mostly dependent on the gamma versus time response, at a given temperature, of a particular emulsion-developer combination. Since other films and developers can be used, particularly in multispectral sensing, two other systems are also shown. Another dependency in the curve shape comes from the location of the energy range within the total exposure latitude of the sensor. The data of Figure 7-2 are based on the 0.3 log exposure range being approximately centered in the average linear response portion of the family of characteristic curves.

7.2.3 Effect of Temperature

Since temperature affects any given chemical reaction in a direct fashion, its control is also very important in the developing function. Each particular developer formulation has a unique time-temperature relationship to produce a specific gamma, with a nominal value at gamma equal to unity. The curves shown in Figure 7-3 indicate this relationship for two typical developers; the developers shown are generally used in small-batch processing. A high volume machine will normally use a specific formulation, such as Versamat No. 641, which exhibits similar properties. The tolerance band indicated is for a +1°F error in developer temperature. If a 15 second error in developing time is accepted, an allowable error in temperature of 2.5°F results. Thus, for black and white film developing, precise control can be somewhat relaxed.

Thus far, a latent image recovery process involving low gamma systems has been considered. The major reason for low gamma systems is to extend the exposure latitude of the film to encompass a wide range of experiment



TIME vs TEMPERATURE FOR TWO DEVELOPER SOLUTIONS

FIGURE 7-3.

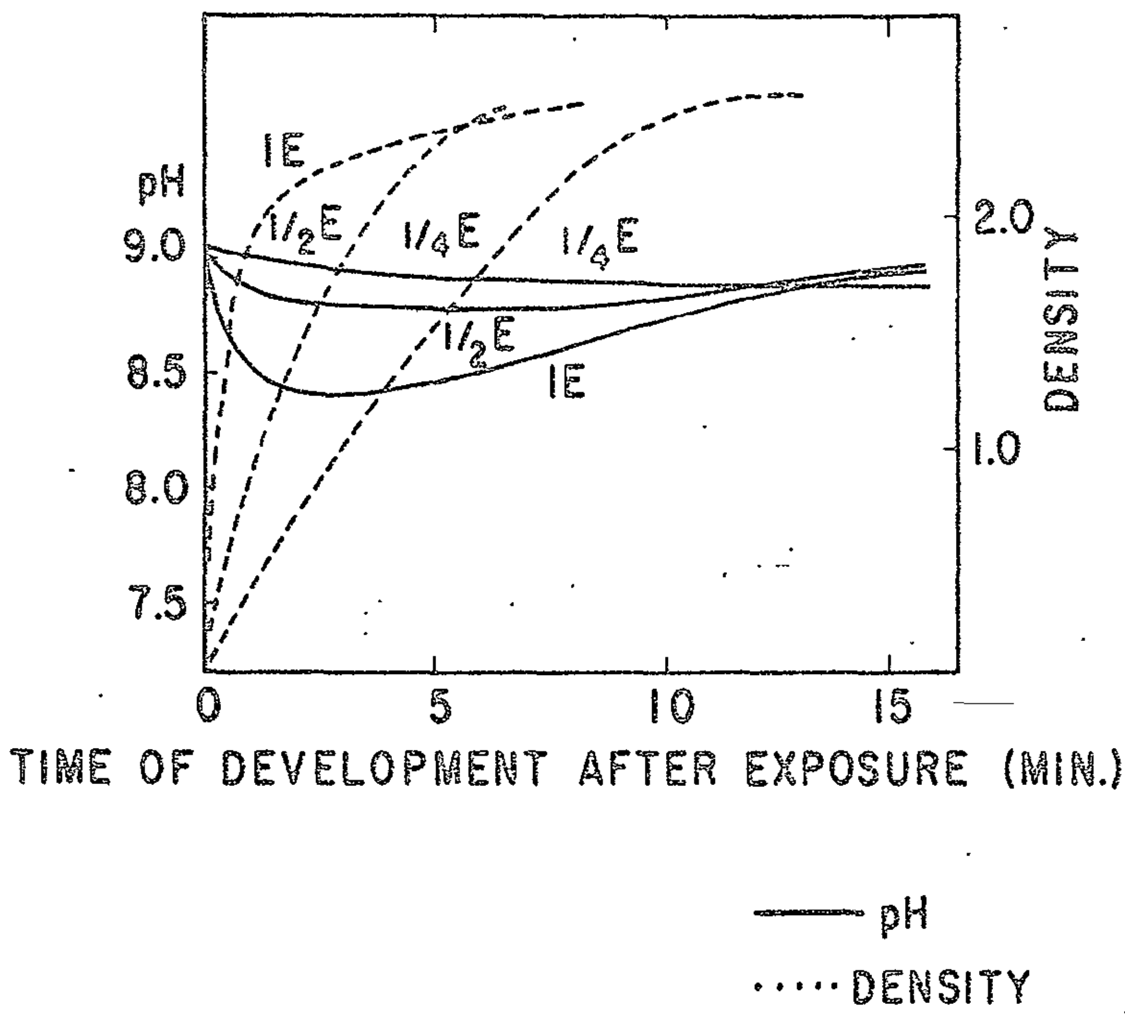
variables. Color emulsions, which operate within a narrower exposure latitude, typically consist of three black and white emulsions integrated in a complex array of support and filter layers. The processed negative, when viewed by projected light, yields all colors in the opposite hue; when reversal processed, the colors will be in the original hue. In order to gain adequate color saturation and facilitate the overall dye solubility process, the emulsion must unually yield a higher gamma. In this case, the first developer temperature must be held to ± 1/2°F, and the second must be held to ± 1°F when the film is reversal processed by the E4 process. Another reason for the more precise temperature control in color developing than that required for black and white film, is the increased complexity of the reaction due to metallic silver being replaced in a dye solubility process.

7.2.4 pH and Agitation Control

All the discussions up to this point have assumed that there were no other variables associated with the kinetics of development. As might be expected in practical film developing, this is not so. In addition to the parameters of time and temperature, one must control the rate at which developing agents penetrate the gelatin. The two major contributors to this function are developer solution pH and agitation.

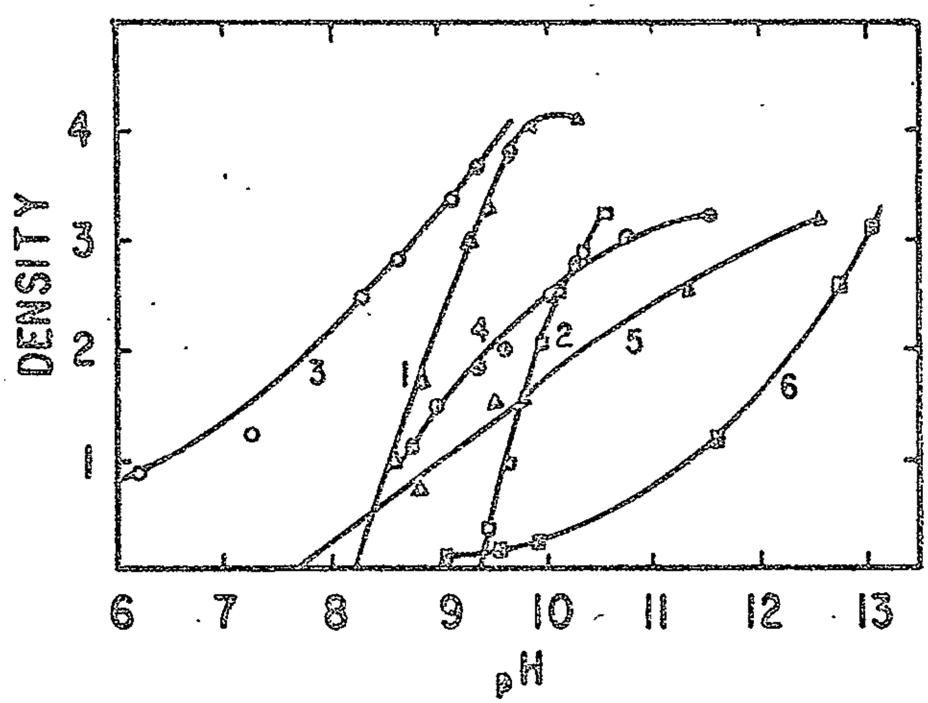
The diffussion of chemicals into the gelatin layer is a complex function. The principal contributor to this activity is the developer pH, which causes a swelling of the gelatin. Certain reactions involve pH values as low as 2.0, but the most commonly used processes involve values of 7.5 to 9.0. The effect of pH is complicated by two different conditions. The amount of exposure received by the film contributes to the activity rate and essential pH of the imbibed gelatin as shown in Figure 7-4. In addition, the activity of each specific developing agent is regulated by the pH of the formulation as shown in Figure 7-5.

Therefore, maintenance of a given developer pH is necessary to produce the desired sensitometric response of the system. Control can be implemented in either of two ways: the time to develop can be increased (roughly a 15 percent increase with every 80 square inches of film) or a specific amount of developer replenisher can be added (the preferred technique).



EFFECT OF DEVELOPMENT TIME

FIGURE 7-4.



RELATION BETWEEN DENSITY AND pH

FIGURE 7-5.

The process becomes more complicated when recovering the latent image in tri-layered color emulsions. Here, the kinetics of development must handle additional complexities due to the multiple gelatin layers. Another factor, which necessitates even more precise control of pH in the color process, is the dye solubility reaction needed to generate the three respective hues.

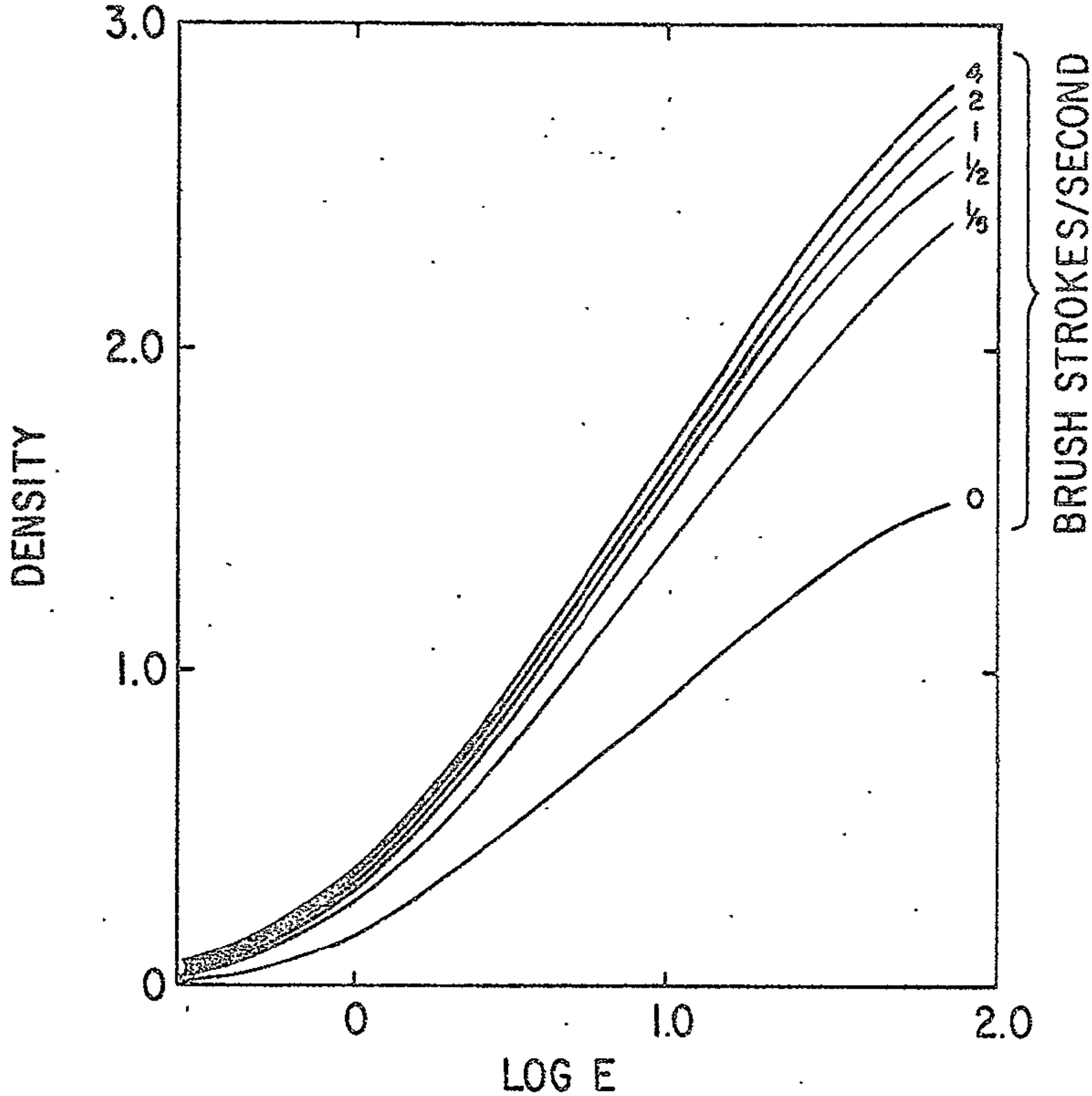
The problem of controlling agitation is a difficult one. It is considered by many to be the single most troublesome facet of the latent image recovery process. The reason for this is that published characteristic curves are always obtained with a specific processing technique. Frequently, a mechanical device is used to optimize agitation, resulting in what is called a "sensitometric processor". This device often does not agitate the developer in a manner equal to that done in a modern high-speed continuous processor. Solving the problem of controlling agitation involves an empirical approach; that is, the method of developing must be calibrated so as to provide consistent, controllable results. Hence, the importance of using pre-exposed, sensitometric data (wedges) throughout the image preprocessing phase.

The need for agitation results from the theory that developer exhaustion occurs in the immediate vicinity of that part of the emulsion where reduction activity is the highest. This brings to light another very important point in the use of the film's sensitometric properties. To obtain uniformity in results, agitation must be performed in a repeatable, controlled manner. Figure 7-6 shows the effect of the degree of agitation upon the characteristic curves for one type of film.

7.2.5 Handling and Cleanliness

Drying is the major contributor to nonuniform film deformation but changes in film size also occur due to machine stresses of all types, particularly in the early part of the development cycle. Although glass plates provide the most stable recording base, they do not lend themselves to high throughput data flow. In fact, the technique of data-ground correlation probably obviates the need for the ultra-stable base that glass plates provide.

To maintain a high degree of cleanliness, clean room techniques are essential. Filtered air flow, gloves, head covering precautions, etc., must be incorporated as integral parts of the routine film handling procedures.



EFFECT OF AGITATION

FIGURE 7-6.

Dust particles must be prevented from entering the liquid development baths; during the drying operation, dust must be kept from falling on the film. Bubble formation, upon immersion of the film into the developer solution, can cause spotting of the film and precautions to prevent, or reduce, this effect are desirable.

7.3 MAGNETIC TAPE DATA HANDLING

The magnetic tape data handled in the preprocessing function includes at least the following sensor and subsidiary data groups:

- Line Scanners
- IR Thermometers
- Scatterometers
- Radiometers
- Spectrometers
- Housekeeping or auxiliary data
- Push-Broom sensors
- RBV-TV
- NAV

The processing flow functional sub-tasks shown in Figure 7-1 are briefly outlined in the following paragraphs. The functions described are strictly signal conditioning operations; this was also true of all the preprocessing steps in film handling, which were discussed in 7.1.

7.3.1 Duplication and Decommutation

The original mission analog tapes begin their preprocessing flow with a copying function, enabling the originals to be stored as pristine information. The tape dupes are then subjected to computer-controlled decommutation whereby the analog signals are stripped from the copy-tape, decommutated and filtered.

7.3.2 Signal Recovery

As the time slices of interest are played back, two data paths are provided. In the first, the FM encoded signals are demultiplexed, demodulated and collected on an output tape for subsequent processing.

Tapes from line scanner or TV sensors, may then be scan-converted for subsequent image screening or held for later reconstitution of the imagery. The non-image radiometer and scatterometer data is digitized to prepare it for computer screening.

The second flow path conditions the PCM information by decoding and formatting it. Data following this path are the outputs from thermometers, radiometers, spectrometers and push-broom sensors, plus NAV readings and housekeeping information.

These two major tape conditioning operations are essentially identical to those presently performed at MSC by special purpose hardware under control of the CDC 3200 computer.

7.3.3 Tape Image Screening

The scan-conversion of TV and line scanner sensor image tapes allows screening of this tape imagery as the next functional sub-task. The screening specialist, viewing the imagery on a TV monitor, enters his decisions into the computer by means of a keyboard. Most of the tapes will be screened in this manner; some will bypass this flow route and enter directly into either the reconstitute or digitization function.

Image reconstitution of the tape image data is one of the three options available at this point; the other two are: analog to digital conversion, and the forwarding of the tape (unmodified) to the correlation process section. At present, the only way to obtain imagery from tape is to run it back through the RS-14 scanner and utilize the film recorder; the other imagers, the RS-7 and Reconofax IV, do not provide tape outputs. The characteristics of the film, on which the tape image is to be reconstructed, are utilized to control the exposing properties of the recording light source. In addition, the source spot-size is adjusted to provide a reconstitution resolution commensurate with the data resolution. The new image is developed in the photo lab and then channeled into the regular film handling route where the operations of reading the reference exposure density values (imaged onto the new film during reconstitution) and film screening, are performed.

The remaining tapes, those not reconstituted or those left unaltered, are digitized in the analog-to-digital function and stacked-up as ØI tapes ready for parameter processing.

7.3.4 Non-Image Data Screening

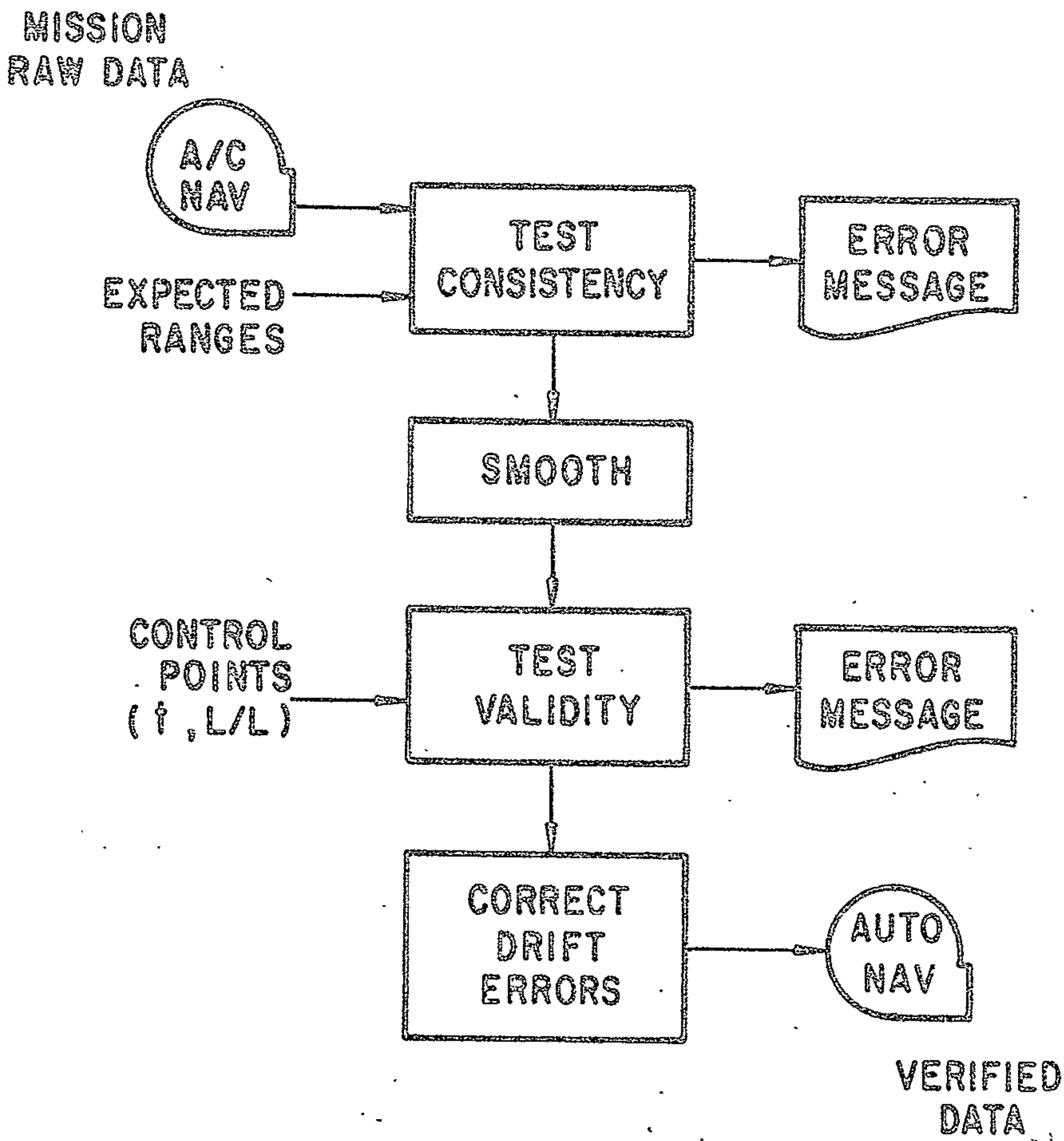
In this functional sub-task, data from thermometers, radiometers and spectrometers, as well as housekeeping information, are screened. Critical data parameters receive a time-history check; if anomalies are uncovered, a time-editing operation is performed to remove the inconsistent entries and produce error message outputs. The corrected tapes are accumulated as ØI outputs and made ready for parameter processing.

Presently, for the scatterometer data processing, hardware electronic filters are being considered for use in the aircraft to decrease the reduction flow rate of 40:1 that is now being achieved by ground-based software digital filtering. An alternative technique, that would still maintain the new expecte ratio of about 2:1, would incorporate hardware filters and digitization on the ground in the preprocessing function. Thus, not only would throughput time be drastically reduced, but more flexibility from an R&D standpoint would also result, since all the data would be preserved by performing the filtering at the ground station (see section 8.5).

7.3.5 NAV Data Screening

Vehicle navigation data must be subjected to a series of tests in order to assure the validity of the data itself and to evaluate the performance of the on-board equipment. Some parameters can be tested and corrected, if necessary, in Preprocessing; others require reference inputs which are not available at this stage of the system flow, so final tests are performed in Correlation Processing.

Initial screening functions are summarized in Figure 7-7. All data values can be tested for time consistency and, if random spikes or holes are found, they can be replaced automatically by interpolated values. Similarly, all readings (including title information-mission/site/flight/line/run, day/month/year) can be compared to their expected range of values and abnormal conditions noted. If there are random occurrences in measured values, or any failure in titling, they can be corrected.



NAV DATA SCREENING

FIGURE 7-7.

These tests should be performed on code block entries for all camera systems and for magnetic tape entries.

Gyro drift errors in the navigational system can be computed and eliminated by using reference control points. Arbitrary points could be derived from mission photographs but at this stage of processing flow the only references available are the Navigator check point entries in the flight log. Hence, these would be entered into the system to verify the automatic record of nadir coordinates.

The procedure is to compare the latitude and longitude of each check point to the latitude and longitude of the navigational system at the same instant of time. The difference in the errors between consecutive check points constitutes a linear error with time. Therefore, given

Check Point	$\dfrac{t_1}{\phi_1, \lambda_1}$	$\dfrac{t_2}{\phi_2, \lambda_2}$
NAV Point	ϕ_{1n}, λ_{1n}	ϕ_{2n}, λ_{2n}

the reference drift corrections are:

$$\Delta\phi_1 = \phi_1 - \phi_{1n} \qquad \Delta\lambda_1 = \lambda_1 - \lambda_{1n}$$

$$\Delta\phi_2 = \phi_2 - \phi_{2n} \qquad \Delta\lambda_2 = \lambda_2 - \lambda_{2n}$$

Finally, the latitude and longitude corrections are:

$$\Delta\phi = \Delta\phi_1 + (\Delta\phi_2 - \Delta\phi_1)\ \frac{t - t_1}{t_2 - t_1} \qquad (7\text{-}1)$$

$$\Delta\lambda = \Delta\lambda_1 + (\Delta\lambda_2 - \Delta\lambda_1)\ \frac{t - t_1}{t_2 - t_1} \qquad (7\text{-}2)$$

The corrected output tape, "Auto. NAV", is now ready for NAV Processing (cf. Section 8.2). The data can also be used to test the code block entries on all mapping systems and the corresponding sensor-associated records on magnetic tape. All such records should be tested and corrective steps taken wherever errors are found.

7.4 SUMMARY OF OUTPUTS

The resultant outputs of the raw data handling, initial conditioning and screening functions, performed as a standard routine in preprocessing on all mission input data, are summarized below. All these products are prepared in proper form for convenient transfer to either parameter, correlation or NAV processing. They include:

- 9 x 9-inch master photo copies
- 70 mm boresight photo copies
- Analog image tapes
- Digital ØI image tapes
- Digital ØI non-image tapes
- Digital "Auto. NAV" tapes.

SECTION 8

PARAMETER PROCESSING

FOREWORD

After mission data has been pre-processed, it must be put through a series of operations which might broadly be categorized as "measurements" and "adjustments". Together, they include five basic tasks:

1) Reconstruct a "best" history of mission navigational data in order to permit later calculation of data-to-ground coordinate transformations (for applications where gross positional accuracy is satisfactory);

2) Correlate mission films with gridded reference imagery (orthophotos) in such a way as to automatically measure data-to-ground coordinate relationships (for applications requiring high accuracy);

3) Adjust density values and/or pixel locations in order to make mission imagery (film or tape) more useful to human analysts/users;

4) Reduce non-image data to meaningful forms (e.g., corrected radiometric profiles, statistical plots, etc.)

5) Perform whatever housekeeping tasks and calculations are necessary to obtain indexing information for subsequent data retrieval.

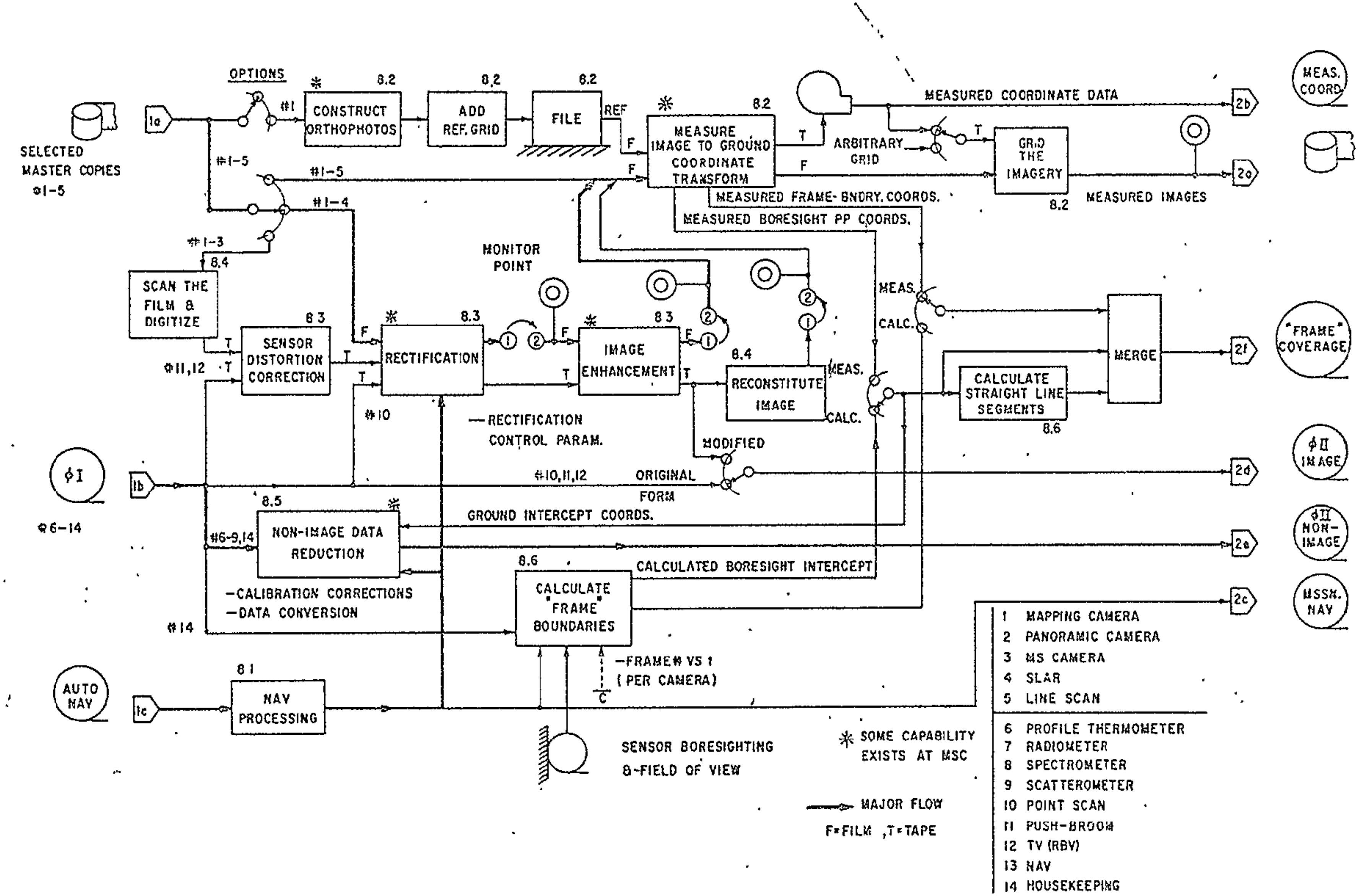
Figure 8-1 depicts the overall flow and subsequent paragraphs discuss individual functional blocks. Note that all imagery must be coordinate-measured before being passed on to Correlation Processing, the next major functional stage. It is, of course, quite likely that this will not always be done - some applications will not require it. And similarly, any functional block might be bypassed in some particular processing task. In fact, the flow sequence might even be altered and new path options developed.

The point is, none of these flow diagrams should be interpreted too literally. They represent what the authors feel to be a typical, reasonable routing arrangement and, to that extent, are valid and useful. However, until such time as considerable hands-on experience has been accumulated on the Pilot System, none of the flow configurations shown (Figures i, 7-1, 8-1, 8-2, 9-1) should be considered "cast in concrete".

SECTION 8 CONTENTS

SECTION 8 CONTENTS
(Continued)

ILLUSTRATIONS PAGE



PARAMETER PROCESSING FUNCTIONS

FIGURE 8-1.

8.1 NAV DATA ADJUSTMENTS

After the Automatic NAV data has been corrected for random errors and drift effects it may be considered "verified"; i.e., all readings are now credible. The next issue to be confronted is whether or not they are usable for the processing application at hand.

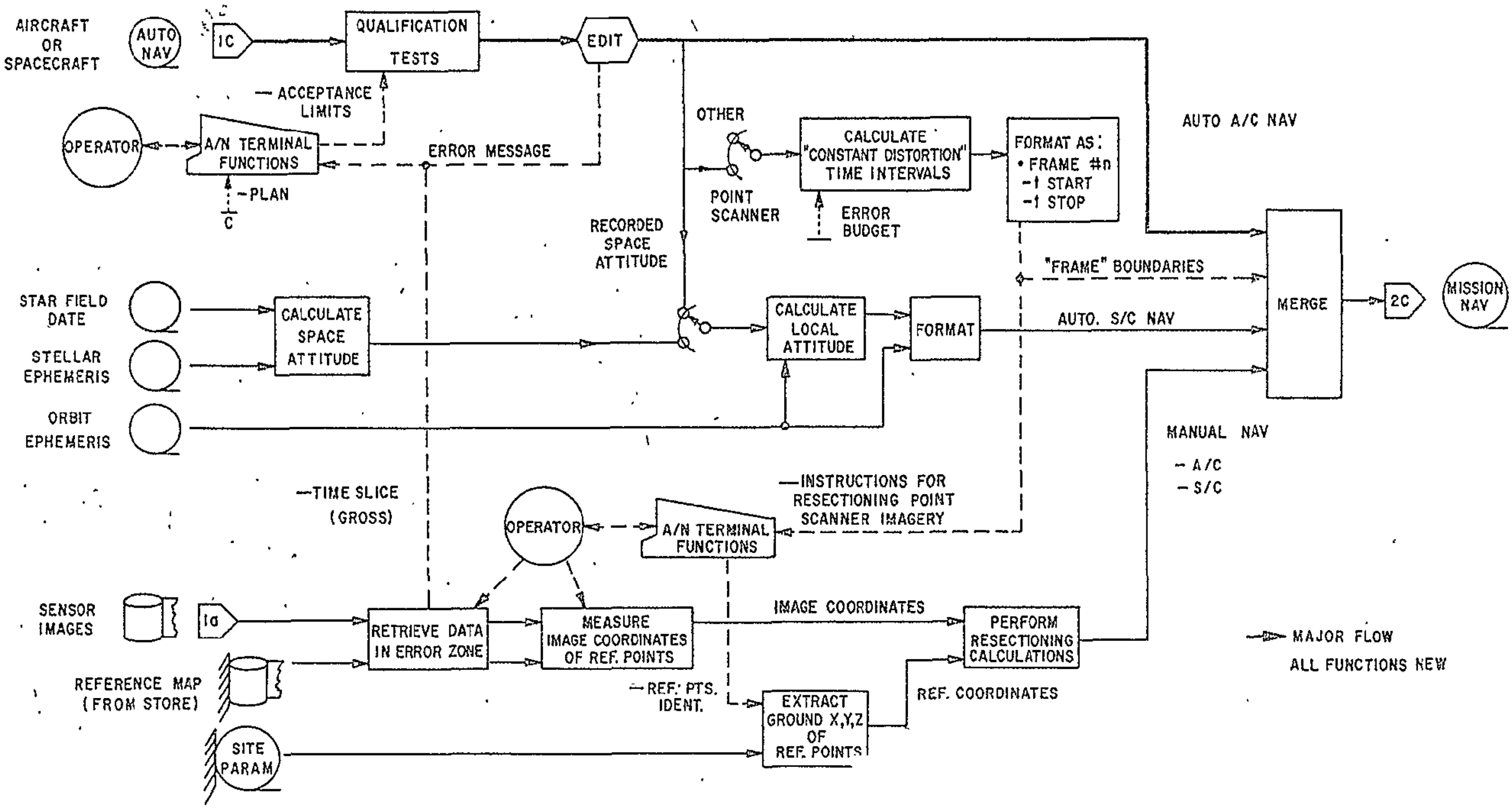
The criterion on which the decision is based is the desired ground location accuracy. Where relatively gross accuracy will suffice, ground coordinates may be calculated from the automatic record of vehicle attitude, altitude and position. However, when accuracy must be precise, alternative approaches have to be adopted. There will also exist marginal cases where some of the Auto NAV data will be acceptable. For example, it it is established that attitude measurements yield a net angle calculation of $\Gamma \pm \mathcal{E}$ degrees, then accuracy in the radial direction falls off as $\pm h \mathcal{E} \sec^2 \Gamma$. Then, inevitably, some applications will require location accuracies which fall in the mid-range as Γ varies from zero to maximum. In those cases, some calculations will be acceptable and others unusable.

The relationship between desired ground accuracy and net angular accuracy can be established as a system reference table and Γ can be converted to limit combinations of pitch, roll and yaw as a function of altitude and local terrain. This reduces the input "Qualification Tests" shown in Figure 8-2 to simple in-or-out-of-limit checks which vary with the application served.

If the location data has not been adjusted by means of the check point fixes (as per the calculations described in Section 7.3.5), then the quantization of Latitude and Longitude to 0.1 minute introduces position errors which can be on the order of ± 600 feet. Hence, the corresponding raw data will be usable only for the very coarse-accuracy applications.

Data which does not qualify should be edited out of the Mission NAV tape and later replaced with derived values. There are two approaches to such derivations:

1) Correlate sensor photographs with orthophotos of the site area and, by performing a controlled tilt and scale adjustment, measure the taking conditions;



NAV PROCESSING

FIGURE 8-2.

2) Perform a resectioning calculation based on measurements of image distances between known ground control points.

The first method has probably never been attempted. However, it is essentially identical to the set-up procedure used in orthophotoscopes. The suggested difference is that one of the inputs be an orthophoto instead of the second half of a stereo pair. One or both holding platens could be moved for the adjustments; in either case, the relative position and attitude become direct measures of the taking conditions for the photograph. The scheme should work, and is likely to be simpler and faster than resectioning, but there is as yet no body of evidence from which to draw quantitative conclusions concerning these factors or the attainable accuracy.

The second method is outlined in the lower position of the diagram. When the time slots of interest have been identified, corresponding photography can be called up. At the same time, the associated auto NAV can be used to identify reference map regions.

In well-controlled data collections, the site area will be carefully surveyed and ground control points marked so that they will appear in the aerial photography. In less well regulated circumstances a human operator will have to visually compare the delivered photographs with some form of reference map (graphic or photographic), decide on a set of at least three, and preferably five, control points per frame, identify them to the system, and carefully measure their image coordinates. Generally, the locations would be particular corners of intersecting roads or streams. Then, having both the measured coordinates and the true three-dimensional ground coordinates, the system can perform the resectioning calculations. These are not included in this report because the approach is:

1) well-known and amply documented in the literature,
2) not recommended.

In the author's opinion, the Pilot System will probably have no need to perform these computations (furthermore, equipment costs alone can be considerable), and the evolving system should pursue the development of correlation methods.

An even more remote liklihood is that there would be a need to attempt resectioning of line scan imagery. Probably, this has never been done and, possibly, it is an impractical task in any production processing stream.

Since the image is a continuous strip whose distortions reflect a time history of aircraft motions, the only way to proceed is to first establish time intervals during which the taking conditions were approximately constant. That is to say, altitude, attitude and track vector should all be relatively unchanged. Then each such interval can be considered to correspond to an image "frame" wherein the perspective distortions in the lateral direction are approximately fixed for all included scan lines. The line scan "frames" could then be resectioned in a manner similar to normal photography, provided the input imagery is first rectilinearized to remove sensor scan distortion. Image measurements in the track direction provide scale information but contribute nothing to attitude determination because there is no perspective distortion in that dimension.

About the best that can be said for the function is that it is plausible; at worst it will, after considerable painstaking measurement and computation, produce specious results. It is definitely not recommended. However, some version of the initial "frame" calculations might profitably be performed in order to generate data indexing information.

If spacecraft data are to be accommodated, another set of calculations must be performed, viz., the determination of local attitude, from a knowledge of orbit ephemeris values and space attitude. The latter might be derived from on-board instruments directly, or calculated from star field measurements and stellar ephemeris data, as shown in the diagram.

At this point in time, there is no requirement to accept input data from any specific spaceborne system, so these calculations are not described in further detail in this report.

The output from this group of functions is a tape containing both automatic and derived NAV data. It represents the best net reconstruction of actual vehicle motions during the mission, and is used in several subsequent processing steps. To avoid confusion between it and the input "Auto NAV"

tape, the output is termed "Mission NAV".

Additional validity tests of the NAV data are discussed in Section 9.8, "Mission Performance".

8.2 METHODOLOGY OF DATA-GROUND CORRELATION

In any automatic method of correlating photographic data with ground detail, a difficult problem exists in determining which ground element corresponds to a given picture element. The fact is that the relative geometric position of elements in a picture correlates very poorly with the relative geometric position of the corresponding ground elements.

The difficulty stems from three basic causes:

- Geometric distortions inherent in the sensor
- Improper angular orientation of the sensor platform
- Height variations in terrain

The first two effects are subject to correction, as described in Section 8.3, but none of the standard techniques eliminates the distortions due to terrain relief. The suggested method, that of image video correlation with a reference orthophotomap, compensates for all three effects and, hence, is a potent tool for establishing the desired data-ground relationships.

8.2.1 Construction of Orthophoto Reference File

By the use of two photographs (a stereo-pair, which is a set of two overlapping views of the same area on the ground) a third photograph can be generated which is an orthographic projection onto a horizontal plane of details in the area common to both stereo pictures. Such an orthophoto should, for the purpose of preserving planimetric accuracy, be produced from pictures taken by a mapping camera having negligible field distortion. Although a detailed discussion of how an orthophoto is made is not pertinent to this study, a description of existing equipments that are capable of producing orthophotos is presented in Appendix C.

Because it is constructed from a planimetrically accurate stereo model, an orthophotograph suffers from none of the three possible sources of geometric distortion mentioned in the preceding paragraph. Hence, it provides a most efficient way of cataloging the precise positions of landmarks, and is ideally suited to use as a system reference for ground areas of interest. The construction of such a file entails three steps:

1. Generate the reference orthophotographs;

2. Superimpose the reference grid system lines on them, and at a pitch appropriate to the local terrain;

3. Annotate them for retrieval purposes and file them:

8.2.2 Image Correlation and Measurement

During the correlation of a mission image with a reference orthophoto, two optical systems are utilized. One of these looks at a small area on the orthophoto while the other looks at a corresponding small area on the input image. Each of these two areas is scanned by a tiny aperture that simultaneously traverses the identical random pattern on both areas. The fluctuating luminous energies intercepted by the scanning apertures during their random sweep are converted into video signals, which are correlated electronically. The motion of the viewing area of one o the optical systems can be constrained to follow any desired path while the movements of the viewing area of the other optical system is allowed to follow that path for which the video signals remain correlated.

By forcing the viewing area of one optical system to follow the overlaid grid pattern on the orthophoto, the second aperture will trace out the corresponding locations on the mission film. Thus a measure of the image distortion is available. But since the reference is a standard ground grid, the data produced (by recording platen displacements) is actually a measured transform from image to ground coordinates. The alternative method of deriving this necessary information is to calculate it via the equations developed in Appendix A.

If the reference grid lines are spaced sufficiently close, intermediate point transforms may be derived by linear interpolation. Obviously, the rougher the site terrain, the smaller the grid spacing required.

If additional apertures are added, and their output signals correlated to the reference signal (ideally, that from the orthophoto but, in general, from any standard image), then the technique can be used to read corresponding data values directly. Thus, multispectral imagery could be converted easily to magnetic tape records which were ordered by ground elements.

If the correlating apertures are further modified so as to permit scribing (e.g., via laser or ink), then the multiband images can be gridded for operator viewing (with a subset of the system grid) while the other correlation functions are being performed. The next paragraph treats this subject for the more general case.

8.2.3 Gridding

In order to assist the analyst, output imagery should be overlaid with some visible grid pattern. This is not necessarily a subset of the ground-coherent reference lines. Any grid can be used, and the particular selections (linear or ground-coherent, and line spacing) can be processing options. As long as the system contains the coordinate relationships between reference grid and output grid, the analyst can be granted a free choice. However, the ground-coherent lines would seem to be most useful.

The ground grid could be scribed on the mission film during image correlation (at every nth intersection, or etc.), but arbitrary gridding requires an additional independent step. Hence, some spotting equipment must be included to mark the film after it has been measured against the orthophoto. For maximum system convenience, it should operate under command of a digital magnetic tape. Then the ground grid or any fixed pattern(s) could be overlaid on the image at that stage in the data flow.

8.3 PICTORIAL DATA PROCESSING

In a broad sense, a picture may be defined as an array of adjacent elements of resolution individually distinguished by four basic properties:

- Size
- Relative position
- Luminance
- Chromaticity
  - Dominant wavelength
  - Purity

Although the processing of pictorial data can be regarded as inclusive of such operations as the generation of orthophotos and the presentation of signature analysis results, its meaning will, for the purpose of this study, be restricted to:

- Sensor distortion corrections
- Rectification
- Image enhancement

Geometric sensor distortion correction and rectification are operations that change both the size and relative position of picture elements. (It is impossible to alter size and relative position independently because the area of any picture must be continuous -i. e., without gaps or overlapping elements.) Colorimetric sensor distortion corrections and image enhancement are defined to include a variety of processing operations, to be specified later, on the luminance and/or chromaticity of picture elements.

The pictorial data processing operations discussed in the paragraphs that follow can be performed on imagery stored on two different kinds of media-photographic film and magnetic tape. In every case a processing operation that can be performed on a film-stored picture can also (via an appropriate computer program) be performed on the same picture stored on magnetic tape. Likewise, a processing operation performed on tape-stored imagery can also be accomplished optically on the same imagery stored on photographic film. However, there are some processing operations that may prove to be more effectively performed on film-stored data while others are more suited to tape-stored data.

It should be noted that only a small fraction of the incoming mission data will be subjected to these functional transforms. Computer manipulation of high resolution imagery is particularly unwieldy because it can require the manipulation of hundreds of millions of data elements per single 9" frame (see Section 8.4.1).

8.3.1. Sensor Distortion Corrections

It is, in general, most desirable that the (proportional) size, relative position, luminance, and chromaticity of the elements of an area on the ground are recreated with fidelity in a picture of this area. In actuality,

pictures encoded in the raw data often lack fidelity because of modifications of the true values on the ground caused by the atmosphere, the taking geometry, ground-relief, and/or sensor distortions. Hence, different forms of processing are sometimes employed to make corrections in the data. Corrections for the atmospheric effects upon luminance and chromaticity of ground elements, for example, will be discussed under "Image Enhancement" (paragraph 8.3.3); while the effects upon the size and relative position of the taking geometry can be corrected by "Rectification" (paragraph 8.3.2).

Sensor distortions can modify the geometric (size and relative position) as well as the colorimetric (luminance and chromaticity) qualities of ground elements.

The following is a list of sensors considered under this study and a description of the distortions associated with each sensor:

Frame Cameras -	Differential phase and amplitude distortions of spatial frequency components of the image due to limitations of the optical system and the photographic recording medium. Geometric field distortions due to the optical system. (In the case of mapping cameras the latter is usually negligible). Luminance and chromaticity distortions of the lens-film combination.
Panoramic Cameras -	Differential phase and amplitude distortions of spatial frequency components of the image due to limitations of the optical system and the film. Geometric scan and lens distortions. Luminance and chromaticity distortions of the lens-film combination.
RBV -	Geometric electron beam deflection distortions. Geometric field distortions due to optical system, although these could be made negligible. Luminance and chromaticity distortion of the photocathode. Spatial frequency distortion by finite scanning spot.

Solid State Array Camera -	Luminance and chromaticity distortions, spatial frequency distortions, and sensitivity fluctuations due to individual array detector elements. Geometric lens distortions, although this could be made negligible.
Point Scanners -	Geometric sweep distortion. Luminance and chromaticity distortions of detector. Spatial frequency distortion due to finite point detector size.
SLAR -	Geometric distortion caused by altitude dependent difference between slant range and ground distance. Spatial frequency distortion due to finite effective beam width and pulse duration.

There are two basic methods that can be implemented to correct for the above mentioned sensor distortions. The first method is empirical. A calibration grid is superimposed on the sensor input so that its metric distortion can be directly measured at the sensor output. To determine distortions in color, a test target of known luminance and chromaticity can be sensed. The sensor output can then be compared with the test target and the proper color correction factors can be derived from this comparison. The other method is analytical. Mathematical expressions for sensor distortions of both geometric and colorimetric origin are derived and applied to correct the sensor data.

It appears that colorimetric sensor distortions are difficult to predict analytically and that it is presently always more practical to apply color-corrections from empirically derived distortion data. Except in the case of multispectral imagery, only the luminance portion of color can be corrected in data recorded exclusively in black and white. In cases where sensors operate in invisible regions of the spectrum the luminance of the image displayed is adjusted to be proportional to the radiant intensity sensed.

Sensor distortions of geometric origin are sometimes quite predictable and analytically derived corrections can be applied to the sensor data. Examples of such cases are spatial frequency distortions due to optical systems and finite scanning spot or array element size, scan distortions of panoramic cameras, sweep distortions of point scanners, and slant range/ground distance distortion of SLAR. Examples of other cases-where geometric distortions are impossible to predict with any reasonable degree of accuracy and where the appropriate corrections must be derived empirically-are optical field distortions of frame cameras, and the electron beam deflection non-linearity of the RBV.

Techniques for correcting sensor distortion can be implemented to operate on pictorial data stored on either photographic film or magnetic tape. The conversion of pictorial data from one storage medium to another is discussed in paragraph 8.4. This is readily accomplished, so a given sensor distortion correction technique is applicable to imagery regardless of whether the present storage medium happens to be film or tape.

Sensor distortion correction techniques that operate on film recorded data must utilize some kind of optical re-imaging method in order to make a photographic record of the corrected data. This re-imaging method must have a means of varying small area input to output magnification for the purpose of correcting geometric distortions, and a means of varying exposure for the purpose of correcting colorimetric distortions. In cases where the image has chromatic components, it may also be necessary to vary the relative strength of different chromatic components of the exposure.

Sensor distortion correction techniques that operate on tape recorded data must incorporate the appropriate computer programs to make the proper changes in the pictorial data encoded on the tape. These computer programs must operate on the addresses of picture elements on the tape in the case of geometric distortion and on the numerical value of picture elements encoded on the tape in the case of colorimetric distortions.

Examples of sensor distortion correction techniques that have been performed on magnetic tape stored pictorial data are the geometric and luminance corrections performed at the Jet Propulsion Laboratory on the digitized television pictures transmitted from the Ranger, Surveyer, and Mariner spacecraft. The geometric corrections applied to the data were

derived from the distorted image of a calibration grid. Correction of luminance distortion was accomplished from inflight data by taking the luminance of each picture element averaged over many frames as a calibrated gray level reading.

8.3.2 Rectification

Assume that a uniform rectangular gridwork composed of identical squares were stretched over the surface of a portion of the ocean or a lake, and that a picture of this grid is taken by a field distortion-free camera the axis of which has been aligned with the local vertical. The gridwork in the resulting picture will also be composed of square sections f/h times the size of the squares in the actual grid, where f is the effective focal length of the camera and h is its height above the grid. This picture of the grid will not only be a rectified photograph, but it will also be an orthophotograph even though it has not been generated from a stereo-pair.

Now, further assume that the image of a rugged ocean bottom composed of underwater mountains and valleys were superimposed on the photograph of the gridwork. The positions of various details on the ocean bottom, when projected vertically to the surface of the grid above, will not correspond to the positions of the same details relative to the grid in the photograph. These positional variations are caused by parallax resulting from the differing heights of the grid and the sub-oceanic terrain, and from height variations in the sub-oceanic terrain itself. Inasmuch as the squares of the grid remain uniform in size everywhere within the field of view, the picture is considered to be rectified in spite of the existing parallax distortion. However, because of this distortion the picture is not an orthophotograph.

It the picture of the grid is taken by a camera the axis of which is misaligned with the local vertical, then the resulting picture of the grid will be composed of trapazoidal areas of non-uniform size rather than squares of equal size as in the real grid. Any picture exhibiting this type of size distortion is considered to be unrectified.

Whenever it is desirable to produce a rectified photograph from an unrectified photograph, effective use can be made of any of a large number of Opto-Mechanical Rectifiers that are designed for this job. Some typical equipments are described in Appendix C.

Basically any Opto-Mechanical Rectifier is a copy camera with a built-in capability of changing the relative orientations and positions of its conjugate object and image planes. Specific models differ in the manner in which this capability has been implemented and in the extent to which the operation of the equipment has been automated.

An Opto-Mechanical Rectifier is composed of three main components - the object platen, the lens system, and the image platen. The orientation parameters that correspond to these components are relative. Hence, any one of the three components may be fixed in orientation (which one depends entirely on the specific equipment design) while the orientations of the remaining two are variable. The question of which component is fixed has no bearing on performance because only relative orientation is significant. Specific values for the orientation settings used to correct a given unrectified photo are derived from mission NAV tape data. (See paragraph 8.1).

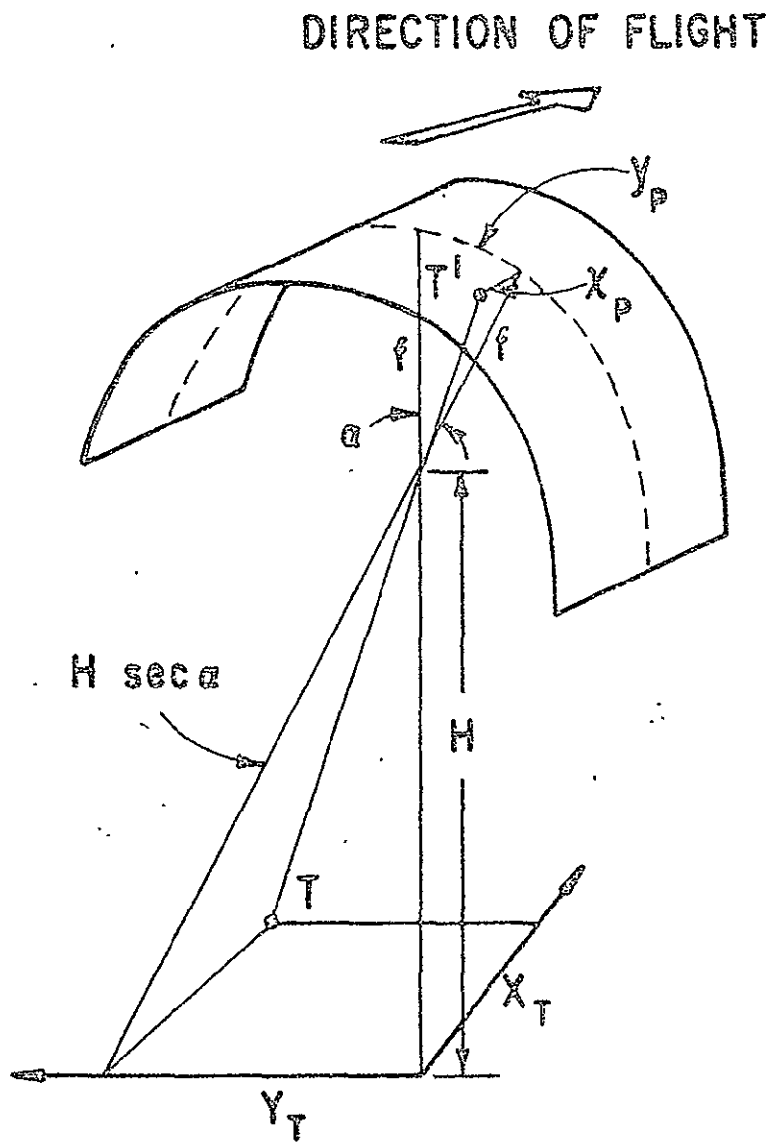
The most complicated type of rectification encountered in aerial photography is that for panoramic camera imagery. Appendix A presents the coordinate transform equations in matrix form. This is convenient in a discussion of computer manipulation of image elements, but it would be useful to examine the geometry here, as well, in order to clarify the necessary operations in an opto-mechanical rectifier.

8.3.2.1 Panoramic Photography

Figure 8-3 illustrates the taking geometry. Three types of inherent distortion are involved:

1) Panoramic Distortion - the displacement of images of ground points due to the sweeping action of the lens and the cylindrical shape of the film platen;

2) Sweep Positional Distortion - the displacement due to the forward motion of the aircraft during the sweep time of the lens. This gives rise to the familiar "S" curve effect;



PANORAMIC GEOMETRY

FIGURE 8-3.

3) Image Motion Compensation (IMC) Distortion - due to the translation of the lens or focal plane which is used to compensate for image motion during exposure time. This displacement is in addition to, and modifies, the first two effects.

There is, of course, only one recorded image but it embodies all of these distortions as an algebraic sum. Define:

$(X_{T'}, Y_{T'})$	=	Coordinates of any image point in the plane of the photograph
(X_T, Y_T)	=	Coordinates of the corresponding point in the ground plane
$(\dot{x}_P, y_P)$	=	Panoramic distortion components
$\dot{x}_s$	=	Sweep distortion component
x_{im}	=	IMC distortion component
f	=	Camera focal length
α	=	Camera sweep angle
ω	=	Angular velocity of the camera sweep
H	=	Aircraft altitude
V	=	Aircraft velocity
v	=	Image velocity in the focal plane
t	=	Time from the start of camera sweep

The panoramic effect is derived by considering only the camera sweep, assuming a stationary vehicle. From Figure 8-3:

$$x_p = \frac{f}{H} X_T \cos \alpha \tag{8-1}$$

$$y_p = f\alpha = f \tan^{-1} \frac{Y_T}{H} \tag{8-2}$$

Now consider the effect of vehicle motion in the direction shown (normal to the camera sweep):

$$x_s = \frac{f}{H \sec \alpha} Vt \tag{8-3}$$

But

$$t = \frac{\alpha}{\omega} \tag{8-4}$$

so

$$x_s = \frac{Vf}{H\omega} \alpha \cos \alpha \tag{8-5}$$

There is no aircraft velocity component in the y direction, so $y_s = 0$.

The intent of the IMC motion is to obtain zero relative velocity of the image during exposure. Therefore, it is introduced in a direction opposite to that of the direction of travel of the vehicle. Hence, $y_{im} = 0$ and:

$$v = \frac{dx_{im}}{dt} = \frac{fV}{H \sec \alpha} \tag{8-6}$$

From the equation for angular velocity,

$$dt = \frac{d\alpha}{\omega} \tag{8-7}$$

Therefore,

$$dx_{im} = \frac{Vf}{H\omega} \cos \alpha \, d\alpha \tag{8-8}$$

and

$$X_{im} = \frac{-Vf}{H\omega} \sin \alpha \tag{8-9}$$

Combining terms, the net displacements are:

$$x_{T'} = \frac{f}{H} X_T \cos\alpha + \frac{Vf}{H\omega} (\alpha \cos\alpha - \sin\alpha) \qquad (8\text{-}10)$$

$$y_{T'} = f \tan^{-1} \frac{Y_T}{H} \qquad (8\text{-}11)$$

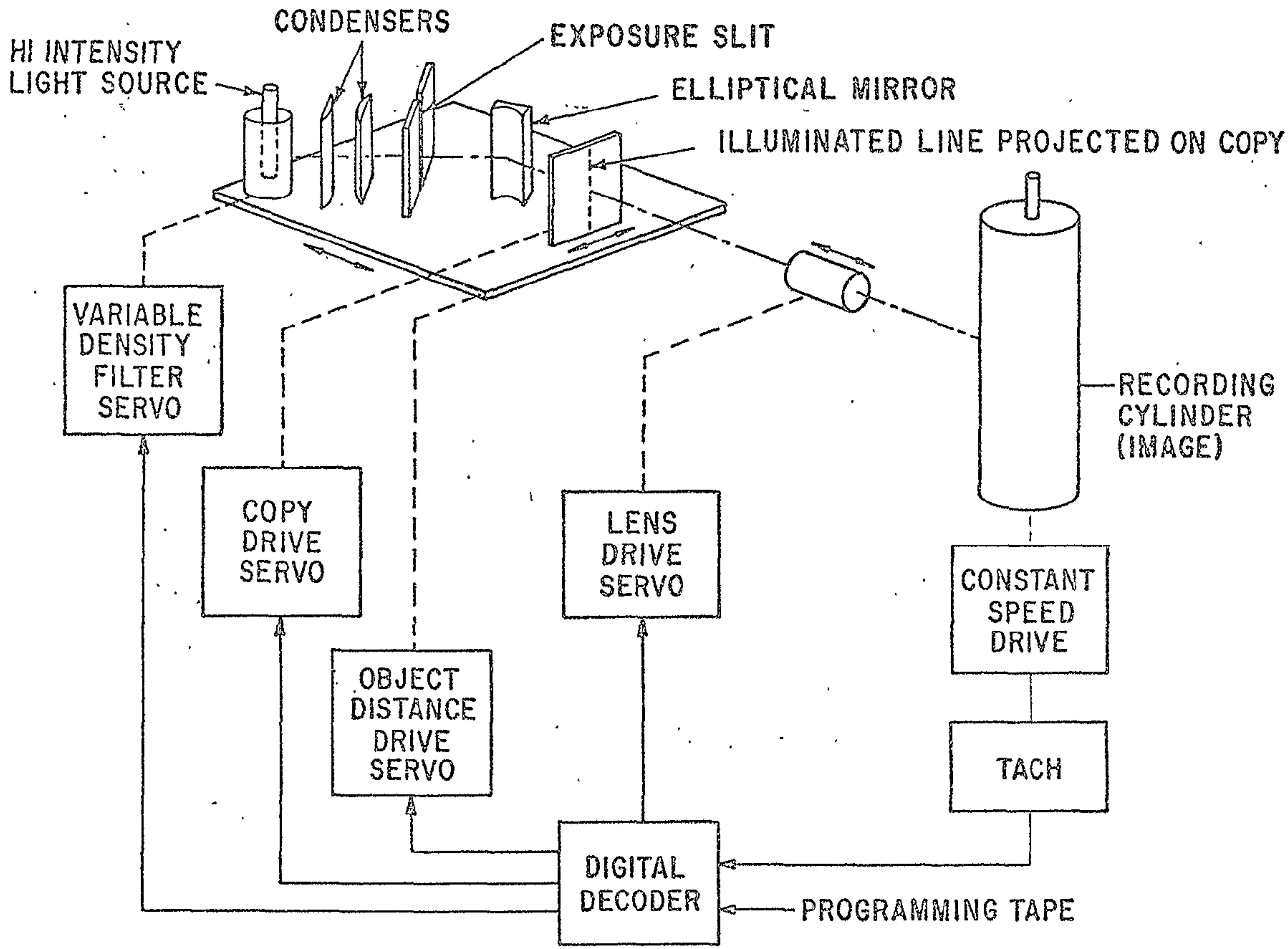
These distortions can be removed, and a corrected image generated, by a computer controlled device such as the Fairchild Electro-Optical Rectifier (shown schematically in Figure 8-4). This machine can rectify practically all types of oblique aerial photography; it is simplest to consider, first, a frame image.

Oblique copy is placed on a flat, glass platen that may be rotated to the correct swing angle. The copy is scanned by a very thin line of light projected from an illuminated slit. A high-pressure mercury-vapor tube is used as the light source and an elliptical mirror images the slit in the plane of the copy. Exposure control is obtained by moving a variable density filter between the light source and the slit.

The copy is moved past the projected slit and as this is done the scanned information is projected to a recording cylinder by a high resolution imaging lens. Rotation of the recording cylinder is preprogrammed to correlate with the rate of scan of the copy by the illuminated slit. In this manner the photographic content of the oblique copy is transferred to the rectified recording.

Rectification in each dimension of the photograph is accomplished by utilizing two different optical techniques. In the direction along the slit (x), the required change of dimension is obtained by correctly positioning the lens and copy. In the direction perpendicular to the slit (y), the required change is obtained by relative motion between copy and recording.

By these means the photographic information is transformed in an optical projection system where the limiting factors on resolution are the resolving power of the projection lens and recording film. Corrections for earth curvature, atmospheric refraction, and film shrinkage can be computed and used to modify the servo drive instructions for the moving elements used in the reconstitution process.



SLIT SCAN ELECTRO-OPTICAL RECTIFIER

FIGURE 8-4.

Panoramic photography is handled in a similar manner. Correction for the typical "S" curve of the principal line of the panoramic picture can be made by moving the copy platen, the imaging lens, or the recording cylinder in a direction parallel to the scanning slit length. This correction would also be computed and programmed into the machine.

8.3.3 Image Enhancement

Image Enhancement is defined to include corrections for defocussing and smear plus those operations on pictorial data that modify the colorimetric qualities of pictures in order to increase interpretability, but excludes those colorimetric operations that have already been discussed under "Sensor Distortion Corrections."

The correction of defocussing and smear is performed by means similar to those used to correct for spatial frequency distortions caused by the optical systems of certain sensors. Correction methods can be implemented to operate on either film-stored data or magnetic tape-stored data. In either case, the optical transfer function of the specific condition of smear or defocus must be computed. The inverse of this transfer function must then be applied to spatial frequency components of the image. In the case of tape-stored pictorial data the inverse optical transfer function is applied by means of computer programming which makes the appropriate changes in the values of picture elements stored on tape. In the case of film-stored pictorial data, coherent optical signal processing techniques can be utilized whereby the image is optically filtered in frequency space by means of a spatial frequency filter matched to the inverse optical transfer function. Figure 8-5 presents one example of this type of enhancement.

Corrections for image smear and defocus must be considered to be operations on the size of picture elements because a significant increase in the total number of discernable picture elements exists after completion of these corrections. There are no forms of Image Enhancement that alter the relative positions of picture elements. However, numerous Image Enhancement operations exist that alter the luminance and/or the chromaticity of picture elements.

Dominant wavelength and purity are both absolute measurements of the value of an element. The luminance of a resolution element, on the other hand, has only relative significance, because it derives its value from its

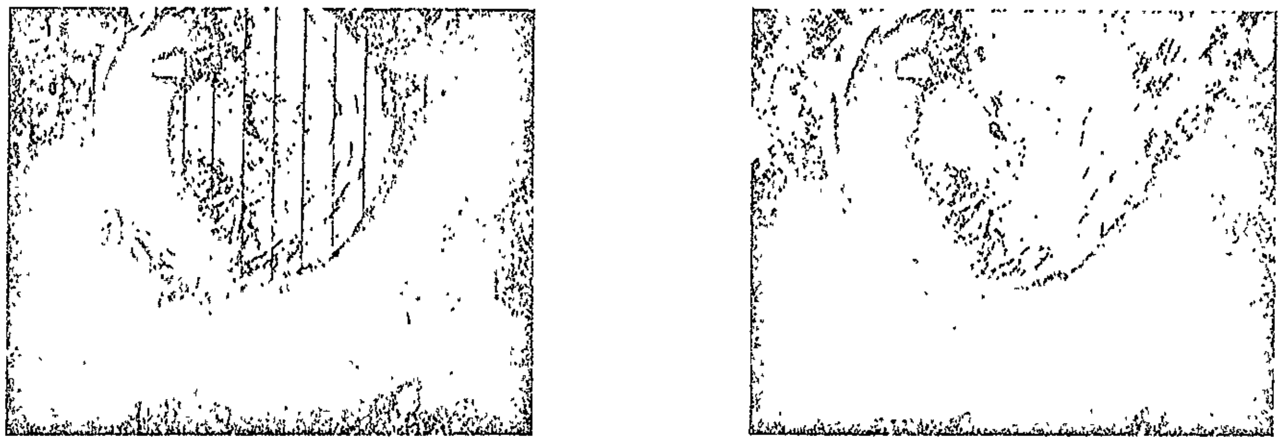


FIGURE 8-5. IMAGE ENHANCEMENT BY OPTICAL SPATIAL FILTERING

magnitude in comparison with its neighboring elements. The luminance of a resolution element on a transparency is proportional to the brightness of the illuminating source. On a video display, the luminance of a resolution element is proportional to the beam current and speed of the scanning spot. As the brightness of the illuminating source of the transparency (or of the scanning spot of the video display) is changed, all elements of resolution that comprise the picture change in the same proportion. The value of any one element of resolution remains unchanged because its brightness relative to its neighboring elements has not been changed. Any significant operation on the luminance of an element must therefore change its value relative to neighboring elements.

One such operation is contrast enhancement. This operation on luminance is required whenever the interpretability of pictorial data is hindered by the fact that practically all the elements in a picture, or a portion thereof, have nearly the same luminance. This condition often occurs when pictorial data is acquired under extreme conditions of atmospheric haze, when an area of almost uniform ground reflectivity is encountered, or when the ground happens to be sensed in that portion of a detector's response which has little sensitivity to variations in irradiance.

When applied to pictorial data, contrast enhancement can take the form of gamma manipulation or unsharp masking. Gamma manipulation consists of multiplying the density of each picture element by a constant. When this constant exceeds unity, contrast is increased, and when this constant is less than unity, contrast is decreased. For tape-stored pictorial data, multiplication by a constant has been performed directly, element by element, by means of a computer program at the Jet Propulsion Laboratory; in the case of film-stored data, gamma manipulation is accomplished by the appropriate adjustment of the development time of the film--with longer than normal development corresponding to constants of multiplication exceeding one, and shorter times corresponding to constants less than one.

Gamma manipulation breaks down when the luminance range of the recorded image is large. Under these conditions, the range of luminance that can be displayed is soon exceeded.

Another method of enhancing small changes in luminance is by contouring, which is the digitizing of the entire range of luminance levels of the recorded imagery. The number of contour levels may be two or more. If only two levels exist the enhancement operation may be called "level slicing".

Contouring is quite an effective technique of enhancement when thermal imagery is recorded on infrared sensitive photographic film. Often the target, which may be land or a body of water, will have only slight differences in temperature. Hence, the density variations in the recorded imagery will be slight. It is possible, nevertheless, to produce a contoured display of the thermal image with a separate contour level for every two degrees centigrade of temperature difference.

Sensors having a limited dynamic range will produce image saturation and contrast reduction. This will occur whenever the range of luminances in the target exceeds the range that the sensor is capable of recording linearly. In most cases large luminance variations do not exist within small segments of target area. Thus, for maximum interpretability, the recorded luminance value of an element of target area need not be related to the average value of luminance of the whole target. It may, instead, be related to the average luminance of a comparatively small area in which it is the central element. This enhancement technique is known as unsharp masking and is used whenever the sensor does not have sufficient dynamic range to record the entire luminance range of the target on an absolute scale. Unsharp masking is similar to the operation of the eye, which has a large field of view, but which relates luminances to the average brightness of the area within the fovial field of view only.

Colorimetric distortions in pictorial data can be caused by the characteristics of the sensor, the correction of which was discussed in paragraph 8.3.1., or by selective spectral attenuation caused by the atmosphere, which is the subject of the present discussion. In addition to the overall contrast reduction caused by haze, there is an additional chromatic distortion in the form of a progressively increasing attenuation towards the blue end of the spectrum. Also, because most of this attenuation is caused by scattering, the scattered light (which comprises the haze) adds a blue veil to the entire picture. Attempts to compensate for these atmospheric effects

by the use of haze filters and contrast enhancement reduce the problem. However, it is impossible to avoid over or under compensation because of the variable nature of atmospheric haze even on a frame by frame basis. Hence, some form of corrective enhancement is required for the colorimetric distortions caused by the atmosphere.

These corrections can be accomplished by employing some means of color calibration. Whatever means is used must have the distorting effects of the atmosphere between the calibration object and the sensor. The calibration object may be a specially constructed target with a suitable range of known colors, or it may be a number of known objects on the ground, the color parameters of which have been accurately measured and documented for calibration purposes.

8.4 TRANSFORMATIONS OF IMAGERY STORAGE MEDIA

Much of the previous discussion has been based on the assumption that any parameter processing method, whether specifically implemented to operate on magnetic tape or photographic film-stored pictorial data, can be applied to both forms of storage. This requires that the film-stored data can be readily converted to a magnetic tape record; or, alternatively, that pictorial data encoded on magnetic tape can be easily converted to a photographically recorded picture. The following two paragraphs describe the methods whereby these conversions can be carried out.

8.4.1 Image Scanning

A library of computer programs for modifying pictorial data, some of which have already been proven from operations on pictures transmitted from the Ranger, Surveyor, and Mariner spacecraft, is currently available at the Jet Propulsion Laboratory. Use of programs such as these requires that the pictorial data to be processed be in magnetic tape form. Hence the use of Image Scanners is necessary for digitally encoding photographic records onto magnetic tape.

A number of image scanners are listed in Appendix C. Basically all employ a light source and optical system to project the image of a small element of film area onto the sensitive surface of a detector. The output of the detector is then digitized and stored on magnetic tape. As the scanning spot is moved over the film element by element and line by line, the entire

photographic image is eventually encoded on magnetic tape.

For some applications, flying spot scanners will be adequate. These provide an ability for very high speed scanning of the imagery (e.g., television rates) but are inherently limited in accuracy by the CRT deflection non-linearity, and in resolution by the CRT spot size. Typical values are spot position to ± 1% of picture height and 4000-5000 spots per sweep dimension.

By comparison, precision opto-mechanical devices can provide on the order of 12,000 elements per 9-inch image dimension, registered to within one spot size throughout the format. However, the time required to scan out an entire 9 x 9-inch frame at this resolution (with existing systems) might be in excess of 2 hours. So an application requiring image scanning at high-resolution and precise registration implies a corresponding system ability to handle over a hundred million picture elements in the course of processing each image frame.

The Scanner spot size cannot be enlarged arbitrarily, to reduce the number of elements, unless the concomitant degradation in effective resolution is acceptable. In general, the diameter of the spot is chosen so that there is a negligible loss in resolution. In practice, the diameter of the spot, in millimeters, is generally taken as:

$$d = \frac{1}{2\sqrt{2}R} \qquad (8\text{-}12)$$

where R is the initial image resolution in line-pairs/millimeter, and $1/\sqrt{2}$ is the Kell factor.

Input imagery (prints or transparencies) can be color-separated by introducing color filters in the optical path. By using dichroic beam splitters and redundant electronics, parallal channels can be established to sense and digitize all the information in one scan; if this is impractical in a particular design, the filers can be inserted for successive scans, provided the scan is geometrically repeatable to within the allowable tolerance.

8.4.2 Image Reconstitution

There are cases in which pictorial data stored on magnetic tape is used as the input to a computerized automatic data correlation program (similar to the one that exists in LARS at the University of Purdue). Image reconstitution from tape records may not be a requirement in such programs. However, whenever the requirement for a hard copy exists for the purpose of human interpretation, image reconstitution from magnetic tape records is required.

A number of image reconstituters are described in Appendix C. All of these employ a light source and an optical system to form a spot image on photographic film. The intensity of the spot is modulated by a signal derived from the magnetic tape record of the pictorial data to be reconstitute As the tape is played back the image-producing spot is moved across the film so that a photographic record of the image is generated element by element and line by line.

The process is exactly the inverse of scanning and the same considerations again obtain: either CRT or mechanical devices can be used, as suitable; and color images (true or deliberately false) can be constructed by the appropriate use of filters. With regard to the latter, it is possible to generate either color separation imagery or a composite on color film. Both arrangements are straightforward on some equipments and, hence, both options are readily available.

As in the case of the scanner (although not specifically mentioned in that discussion), the ultimate system component should be able to handle roll film, at high-speed and high-resolution and with a registration accurac on the order of one-half a spot diameter.

8.5 NON-IMAGE DATA REDUCTION

This fundamental block, shown on Figure 8-1, represents the set of calibration correction and data reduction operations which will be performed on the recordings from non-imaging sensors. The latter include:

- Profile Thermometer (IR)
- Spectrometer
- Microwave Radiometer
- Scatterometer Radar

By and large, the processing will be identical or very similar to that currently performed in the Houston ground operation which supports the on-going aircraft program (cf. Reference 1 in the Bibliography). Consequently, it will not be described here.

The only point warranting comment is a suggested modification to the arrangement for frequency filtering the scatterometer return.

An MSC briefing indicated that the initial approach, of digitally filtering the returns via a software routine, was being abandoned in favor of hardware filters. This is an excellent step which should substantially improve the processing throughput rate. However, as of this writing, the plan appears to be to install the hardware in the vehicle and filter the composite signal return prior to on-board recording. This may then allow some bandwidth reduction as a side benefit, particularly if R&D activities eventually disclose that the information of interest can be derived from examination of only a few critical scatter angles.

On the other hand, this has not yet been established (except, possibly, for sea-state determination) and the on-board filters, once chosen and inserted, are:

1) susceptible to failure
2) fixed, and thereafter totally characterize the data collection
3) tuned for a specific ground speed

Therefore, a change in velocity, although it might be measured and known, produces an unalterable shift in scatter angle of the data, and a component failure in a filter irretrievably loses a segment of the take. A recorder failure will, in any scheme, result in a data loss but why add filter problems if there is sufficient bandwidth available to record the raw analog signal?

If the hardware filters are located on the ground the mission tape can be played through them to produce identical data for reduction processing. But in addition:

1) failed units can be replaced and the mission tape re-run through them;

2) other filter combinations can be used for R&D purposes;

3) theoretically, velocity changes can be compensated by programmed filter tuning or changing;

4) the analog signal can be screened for frequency components outside the normal range.

One application where the latter feature might be useful is in the detection and analysis of tsunamis. The moving wave should produce a doppler shift proportional to its velocity. In deep sea, this can be as high as 500 knots so, depending on the angle of interception, the return frequency could shift enormously in either direction. Thus, assuming the scatterometer receiver, the data recorder, and the intervening circuitry are capable of passing the shift, a usable measuring device is already in hand.

8.6 "FRAME" BOUNDARY CALCULATIONS

It is imperative that an effective data indexing scheme be incorporated into the system to facilitate retrieval operations. Sensor collections must be extractable from both mission and time-history files and search time kept to a minimum. This can be done only if an accurate measure is taken of the per-mission sensor coverage, and the values related to a reference ground grid. The first step requires that all sensor data be grouped and each set characterized, and is the procedure described here; the subsequent conversion from descriptors to Index File material, and the search process itself, are discussed in Section 9, "Correlation Processing".

For indexing purposes, four classes of data can be identified:

1) Frame imagery
2) Panoramic photography
3) Strip imagery
4) Profile data

Figure 8-6 summarizes how they would be grouped and tagged.

Frame Images from mapping cameras, multi-spectral cameras or TV-type systems, such as the RBV, require that ground coordinates be recorded for the 4 corners of each frame. Boresight photos (assuming they are used at all) can be described by noting the coordinates of only the principal point on each frame.

Panoramic Photography is slightly more complicated case because the ground coverage per frame has distinctly non-linear border lines. This could either be ignored in the gross search stage or the process could be refined by establishing ground coordinates for intermediate points as well as for the frame corners.

Strip Imagery from point scanner, SLAR and push-broom sensors can be handled conveniently by defining the fixed-condition "frames" discussed under "NAV Data Adjustments". Ground coordinates at either end of the scan must be determined for each designated time mark. Consecutive sets define the "frames".

Profile Data trace out curved ground intercepts, such a shown in part (d) of the same Figure. Therefore, a convenient "frame" here is an approximate straight line segment. Looser accuracy tolerances could be used to independently calculate profile data segments, or the same time intervals as established for strip imagery could be employed here also.

If well-aligned boresight photography is available, then all of the necessary ground coordinates, for all sensors, can be derived either by measurement (via image correlation with marked orthophotos) or by computer calculation (see Appendix A).

In either case, appropriate descriptors must be developed for the entire mission collection, then the data merged and passed on toward an eventual entry into the Index File.

8.7 DATA BASE INTERFACE

It would be premature at this stage of the system design to specify any details of the interface between the Automatic Data Correlation System

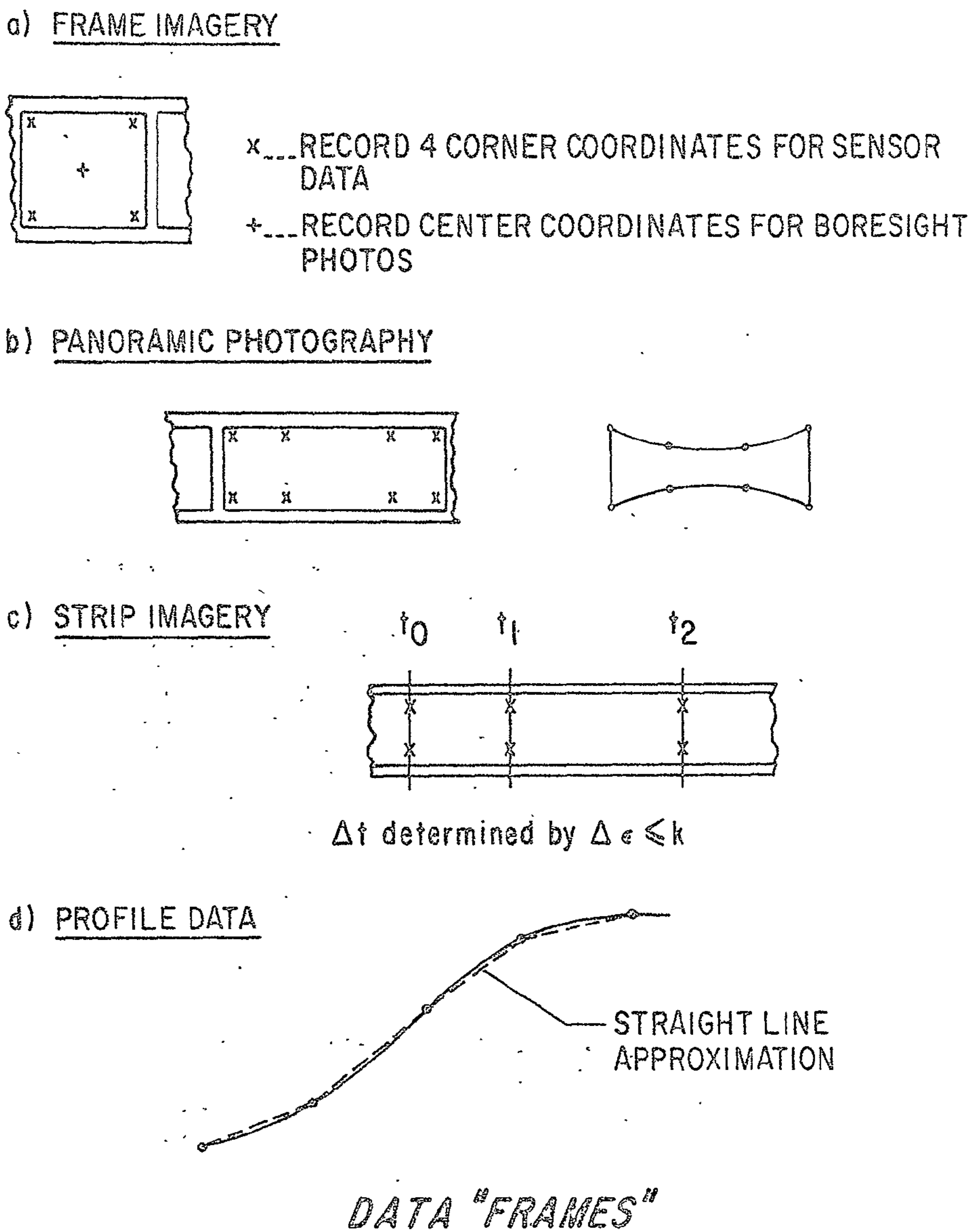

a) FRAME IMAGERY
x...RECORD 4 CORNER COORDINATES FOR SENSOR DATA
+...RECORD CENTER COORDINATES FOR BORESIGHT PHOTOS
b) PANORAMIC PHOTOGRAPHY
c) STRIP IMAGERY
t_0
t_1
t_2
Δt determined by $\Delta \epsilon \leqslant k$
d) PROFILE DATA
STRAIGHT LINE APPROXIMATION
DATA "FRAMES"

FIGURE 8-6.

and a Central Data Base. Interface continuity is a topic unto itself which will have to be analyzed when the user service requests have been better defined and the processing subsystems are well understood. Nonetheless, a few comments are in order.

The first has to do with the influence of function on form, content and redundancy. It is clear that an archival storage is necessary to retain original mission films and tapes and probably also the master copies of each. It is not at all clear yet what the proper storage arrangement of processed data should be. Certainly, there will be high density computer-compatible tapes and certainly there will be microfilm records of output imagery, plots, tabulations and reports. But there are related questions that must be resolved:

1) Should intermediate products that are formed part way down a processing chain be stored also? Permanently or temporarily?

2) The possibility of eventually accommodating large numbers of on-site users suggests that redundant image storage might be useful, as in a more conventional library. But is this feasible when huge amounts of data are involved?

3) Are there access techniques which can ameliorate the difficulty posed in (2) above? For example, "browsers" might be initially serviced by a video pickup and disc storage.

4) Should some data be stored in video form automatically, as a normal procedure? which? when? why?

5) Is it necessary to store computer generated images (alphanumerics and graphics) when the control tape that generated them is on file and display consoles are available?

The list of such questions can be extended considerably. But it should be apparent, even from this sampling, that the most important key to all decisions is a very specific delineation of the services to be rendered to each type of user.

The fundamental organization of the material in the Data Base is similarly determined by the nature and flexibility of those services. It is pointed out in Section 10, " Library Functions" , that the overall system might profitably be used in various planning and analysis tasks as well as for the per mission processing. If so, then sensor and summary data might be grouped according to classifications such as:

1) Program Summary

- Progress toward national goals
- Participating agencies
- Analysis of user community
- Coverage to date
- Service volume
- Projections
- Planned experiments
- Unanswered requests
- Other reports

2) Sensor Utilization

- Relative success per type of application
- Performance histories on all equipments
- New design recommendations
- D&D program summaries

3) Site Files

- Site parameters
- Time history per item (crop identification, status, yield, etc.)
- Area analysis reports
- Mission list
- Sensor data index

4) Topic Files

- Item signatures
- Site list
- Mission list
- Sensor data index
- Related documents

5) Mission Files

- Summary report
- Data tapes and film
- Coverage index
- Output masters

6) Archives

- Original mission tapes and films

Then there is the management problem. Section 5 noted that the entire service facility should be linked to a comprehensive Management Information System. It will be some time before that can be designed in any depth and one of the major ambiguities to be cleared is the scope of its control and flexibility. That can vary the size and complexity of the software package enormously, resulting in considerable impact on necessary storage space and equipment interfaces. But another point is evident, too: there is no single interface between the ADCS and the Management System. Every piece of equipment will (ideally) report its operational status, and all computer operations will be performed under executive control. Presumably, all software will be stored in the Central Data Base but whether that becomes fact or whether it is distributed over several locations, it functionally permeates the total operation.

It seems unlikely that very many of these considerations will seriously affect the Pilot System. There will probably be no sophisticated Central Data Base during the life span of the first-phase Data Correlation System. Nor should there be.

However, even that low-volume configuration will generate some products, so a beginning should be made toward establishing a streamlined file organization . But that requires some hands-on experience and specific design planning. About the most that can be said at this point in time is in regard to certain index calculations that seem likely to be necessary. These are treated in Section 9.1, "Construction of Index Files."

8.8 SUMMARY OF OUTPUTS

Outputs from the Parameter Processing Section are passed on to Correlation Processing. At this point, all "measurements and adjustments" have been made and the data products to be transferred are as follows (cf. Figure 8-1):

Connector	Form	Description
2a	9" film	Prime Sensor Images
	70 mm film	Boresight Photographs
2b	Mag. tape	Measured Coordinate Data
2c	Mag. tape	Mission NAV
2d	Mag. tape	ØII Image Data
2e	Mag. tape	ØII Non-Image Data
2f	Mag. tape	"Frame" Coverage Data

SECTION 9

CORRELATION PROCESSING

FOREWORD

The third major group of system functions is concerned with pulling together the disparate elements of processed mission data and converting them to usable forms. Six activities are involved:

1) Construct an efficient Index File;

2) Extract mission data subsets and/or historical files for further processing (Signature System analysis, Time History analysis, etc.);

3) Provide properly formatted data to the Signature Analysis System;

4) Perform whatever output transforms are needed to convert various data sets into synthetic combined forms (false color, symbolic overlays, etc.);

5) Evaluate the mission collection with respect to sensor performance and satisfaction of mission objectives;

6) Prepare a composite mission output package for review and eventual dissemination to the user community.

The functional flow which relates and details these activities is shown in Figure 9-1.

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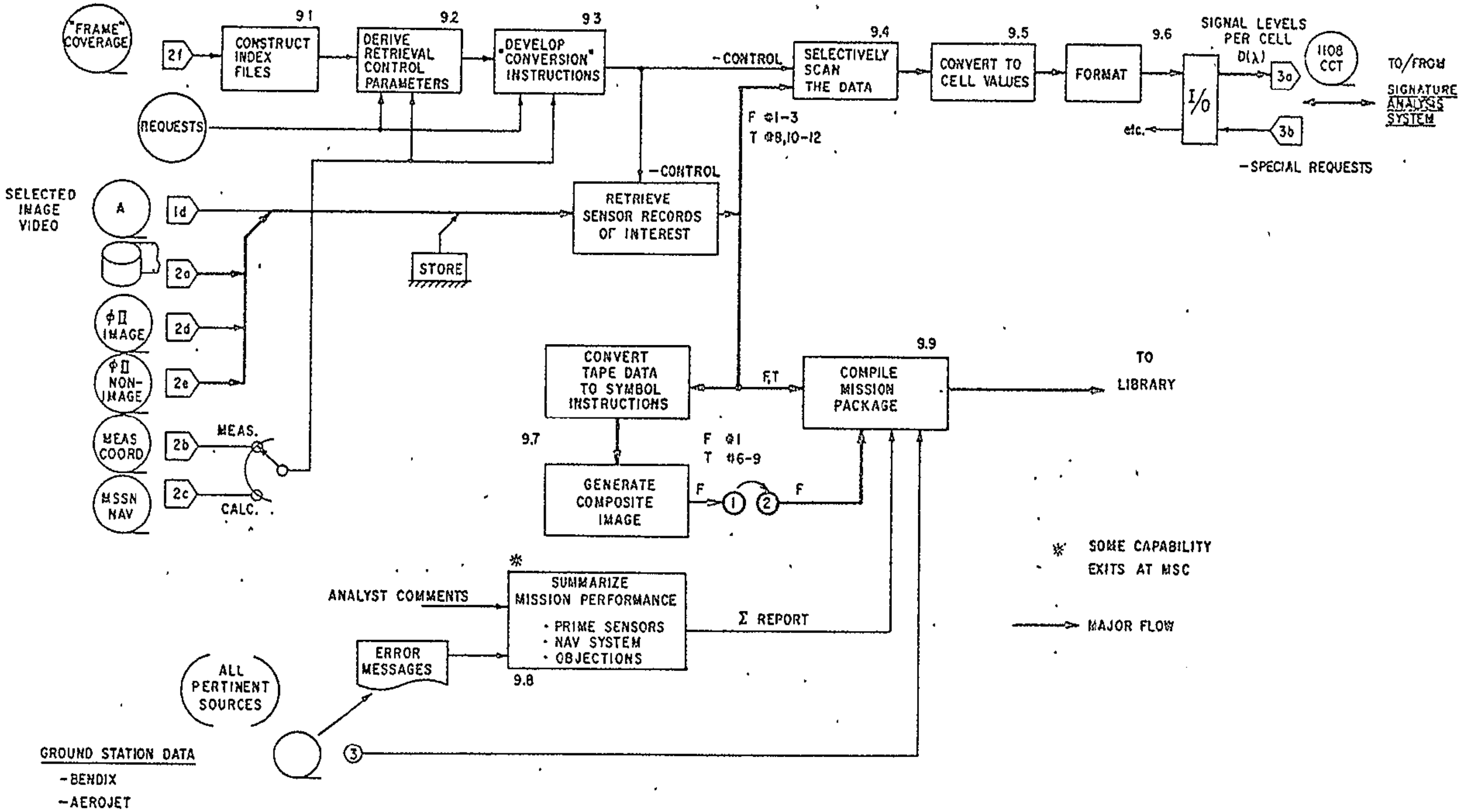
SECTION 9 CONTENTS
(Cont.)

ILLUSTRATIONS		PAGE



CORRELATION PROCESSING FUNCTIONS

FIGURE 9-1.

9.1 CONSTRUCTION OF INDEX FILES

"Frame" coordinates from Parameter Processing summarize the mission coverage, sensor by sensor. Therefore, given a "frame" identification, the system will be able to identify the ground region seen. But the first interrogation to be handled will almost always be put in exactly the reverse order: given a ground area of interest, what data has been collected on it? Consequently, further indexing calculations are necessary.

The recommended general approach is the following sequence:

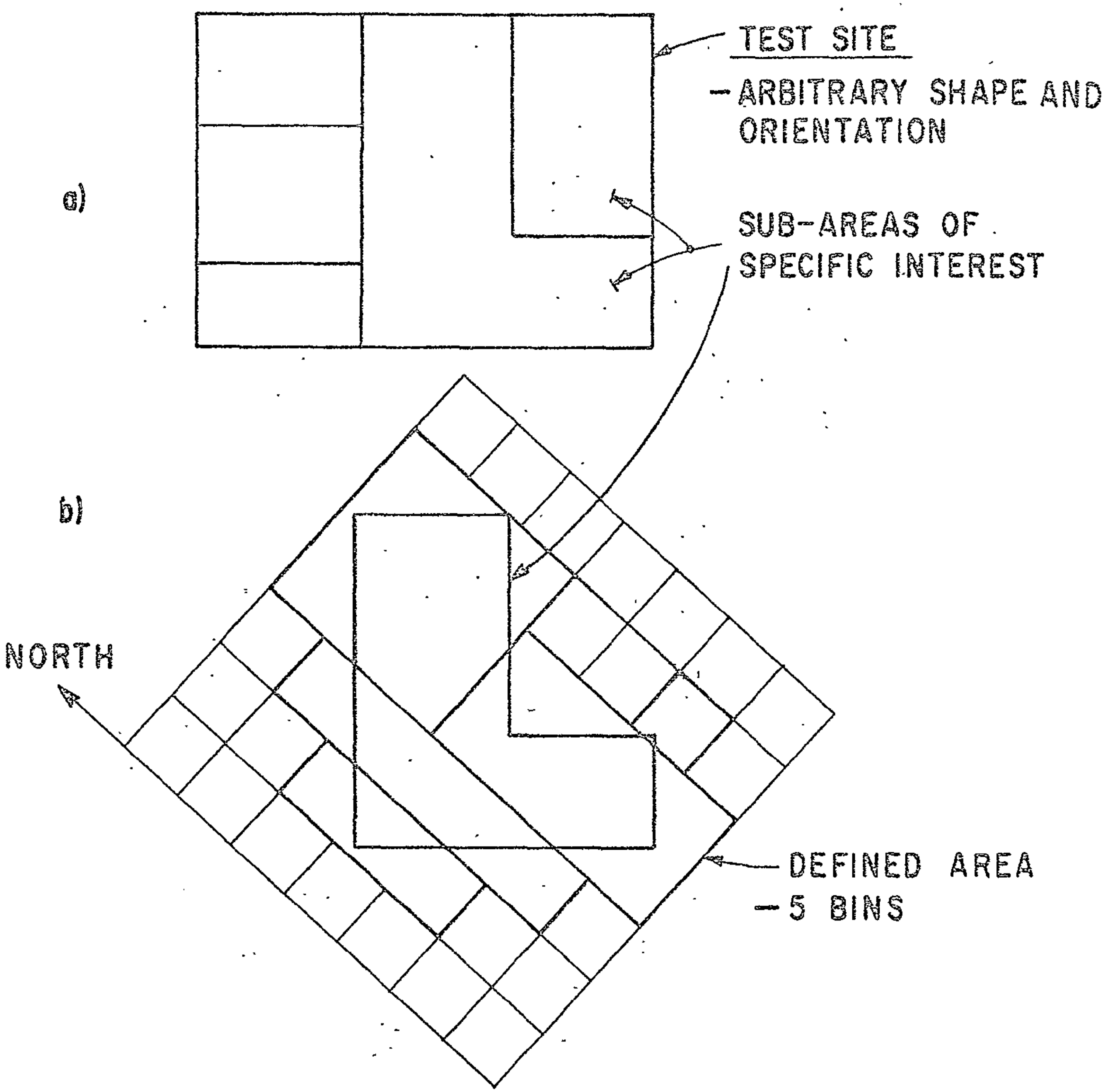
1) Since a "mission" can include one or more overflights of several site areas and the collected data can be processed for different applications, first decompose the nominal coverage into independent sub-areas of interest. That is, each processing request should have an associated ground region of specific interest. Separate regions may or may not overlap.

2) Divide each arbitrary sub-area into constituent rectangles on the local ground reference grid. The grid pitch can be made as fine as desired, so free-form sub-areas can be described with high accuracy if there is any need to do so. It is expected that gross forms will be adequate and, in any event, it seems most desirable to retain the integral-number-of-elements approach to defining area. (See Figure 9-2.)

3) Given the sensors of interest and the mission time range of interest (if specified), calculate film (or tape) footage to the target area as per Appendix B, then test "frame" coverage against the rectangular ground areas, or "bins".

4) Store the fact of each partial or total overlap of a frame and a bin by tagging the bin record with the frame number and vice-versa.

5) After all frames have been tested, combine bin records into corresponding sub-area site files.



DEFINITION OF GROUND AREA

FIGURE 9-2.

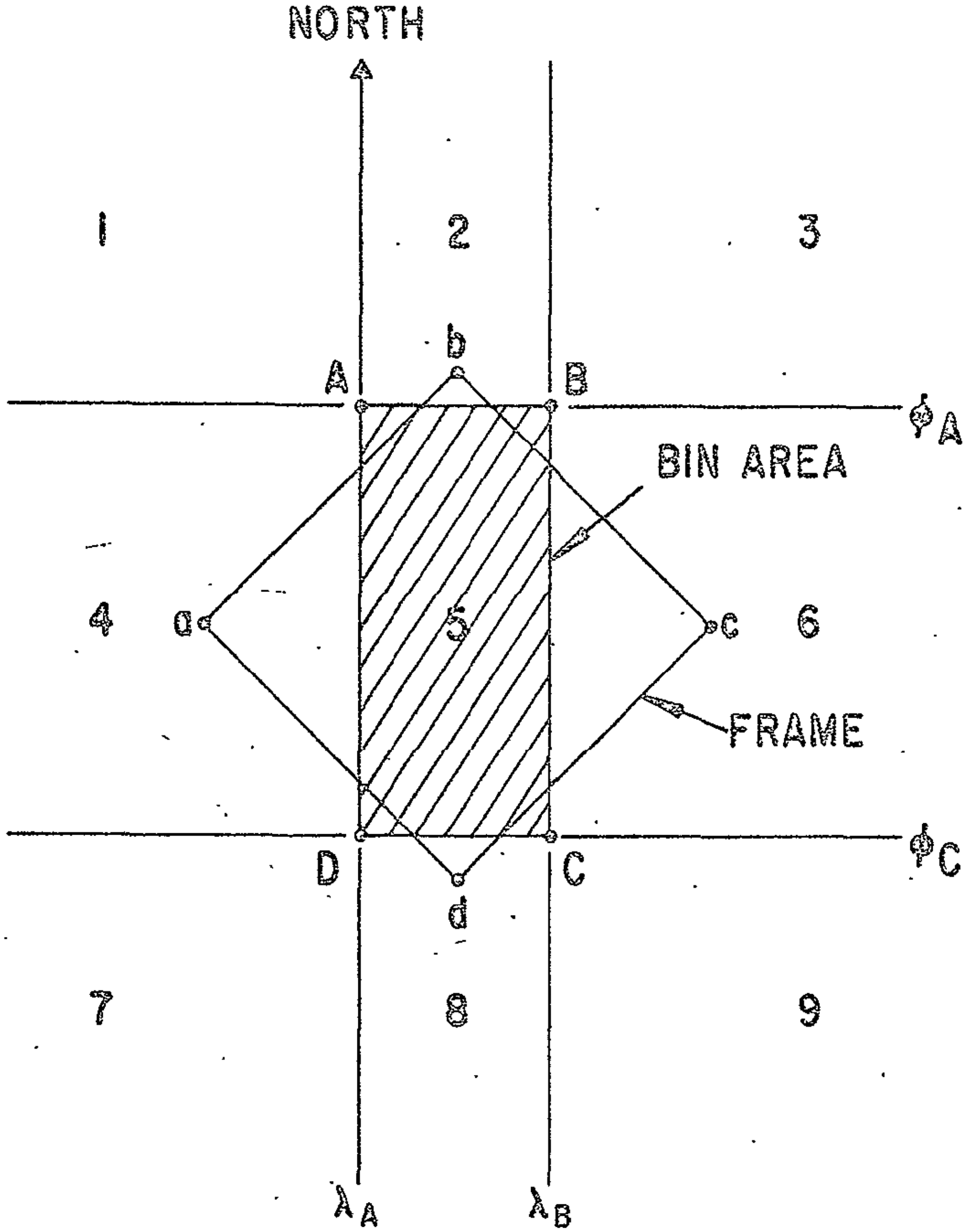
At this point, the sub-area files will identify all data sources (sensors and frame numbers per mission) that contain relevant information. The exact overlap pattern is not important yet. That is a second-order calculation which should not be performed until the processing request has been focused to a considerably narrowed portion of the total data.

Considering that both aircraft and spacecraft collections must be accommodated, it is clear that either bins or frames could appear as the larger unit. If all bins are larger in all dimensions, then it is sufficient to check only the frame corner coordinates in the overlap tests. The converse also holds if all frames are larger in all dimensions, but the test is unwieldy because bins are aligned with the ground grid system whereas frames are not.

The test becomes more complex if the frame and the bin each have a longer dimension. Then cases can arise where no corner of either falls within the area of the other and the problem becomes one of determining whether any boundary line of the frame crosses the bin region.

Consider a situation such as shown in Figure 9-3. By extending the boundary lines λ_A, λ_B, ϕ_A, ϕ_C of the bin area, the grid space can be divided into nine zones, as indicated. Then some decisions regarding frame edge (vector) intersection of the bin (zone 5) could be made immediately with the following truth table:

Vector End-Point Zones	Intersection	No Intersection
1-2		X
1-3		X
1-4		X
1-7		X
2-3		X
2-8	X	



PARTIAL BIN/FRAME OVERLAP

FIGURE 9-3.

(continued)

Vector End-Point Zones	Intersection	No Intersection
3-6		X
3-9		X
4-6	X	
4-7		X
6-9		X
7-8		X
7-9		X
8-9		X

If no frame edge vectors do intersect the bin, and if all four do not produce "No intersection" tags, then boundary intercept calculations would have to be performed. This is a hypothetical case conditioned by a special range of dimensional relationships between bins and frames; i.e., neither can totally include the other, or the "No intersection" tests become meaningless. But there will probably be very few instances where this special range will be known to apply and they are certainly too esoteric to warrant additional computations to discover them. Moreover, of the 28 possible zone combinations, 14 are determined as indicated but the other 14 require further calculations. Finally, there is a still more complicated general case which also involves boundary intercepts and can be viewed as including this type. The two "positive" tests (zones 2-8, 4-6) are useful, however, so the general procedure should be:

1) If frames are smaller than bins in all dimensions, test whether any corner falls within bin limits;

2) If the dimensional relationship is marginal or if frames are larger, test whether any set of consecutive frame corners lie in zones 2 and 8 or 4 and 6;

3) If the decision is still indeterminate, go to the next general case.

The most complicated case arises when a frame can include parts, or all, of more than one area bin. Since the bins are aligned with the ground grid, any configuration can be defined as a known sub-set of a uniform small element array, so a general situation can be depicted by an arrangement such as shown in Figure 9-4, for frame photography.

Bin identities for the four corners would be established first. Then the computation might proceed by calculating the intersection of frame boundaries with bin row boundaries, tagging the adjacent bins in each column (the shaded squares in the drawing), and deducing the included bins by filling in all columns between tagged ones in the same row. This is quite straightforward and is described in Appendix B.

Panoramic photography would be handled in exactly the same manner except that the frame boundary could include more than four straight line segments. Profile data calculations need consider only the intercepted bins since ther is no included area.

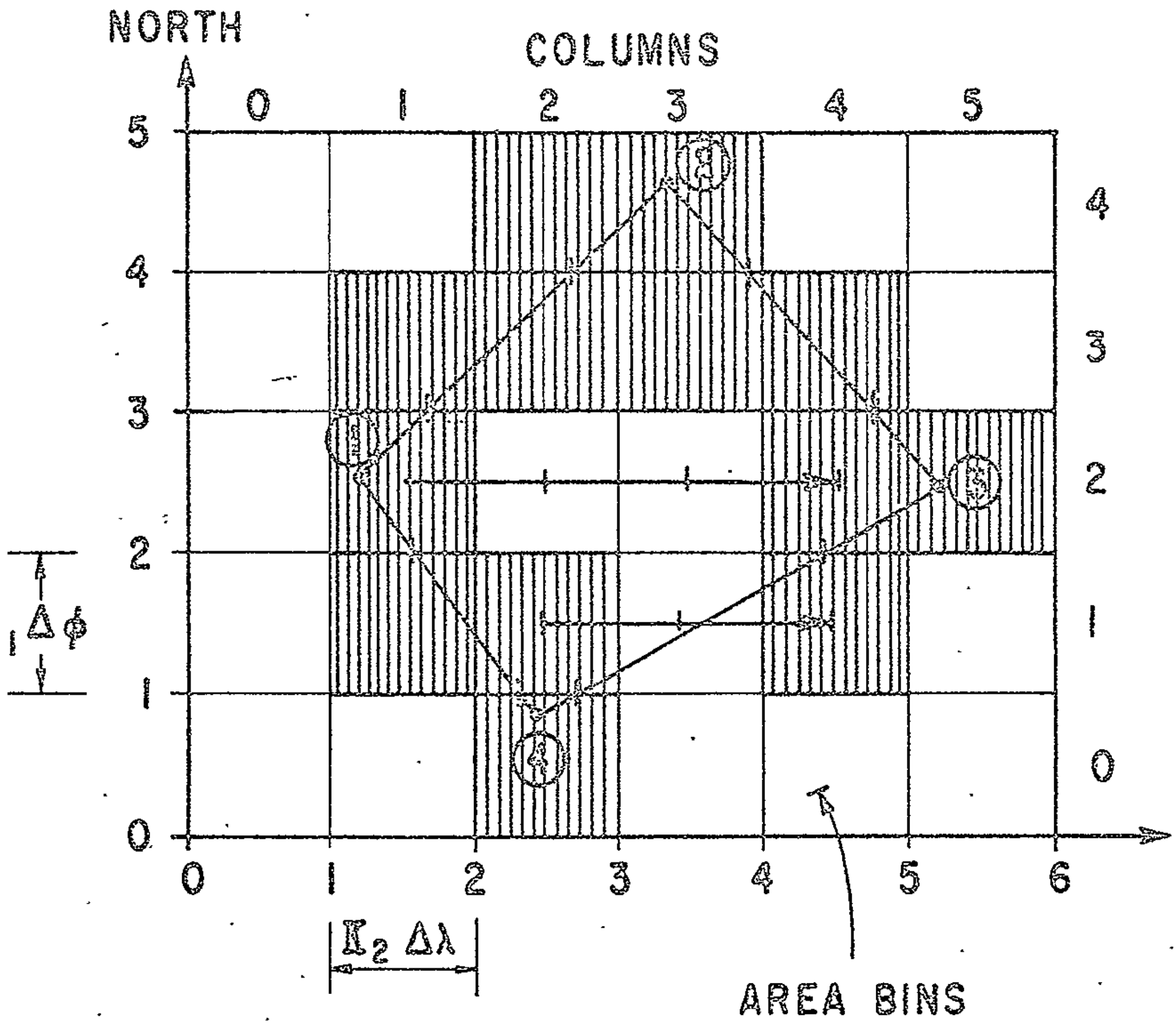
Once the coverage information has been developed, the remaining step is to re-sort it and assemble it on the original "sub-area of interest" basis. Then the Index File will contain:

1) Coverage Table

   - ground area units (bin numbers) associated with each data "frame"

   - ground coordinate boundary descriptors for each "frame"

   - time per "frame"



COVERAGE OF A PHOTOGRAPHIC FRAME

FIGURE 9-4.

2) Site Table

- sensor "frame" numbers associated with each bin
- bin numbers for each sub-area of interest

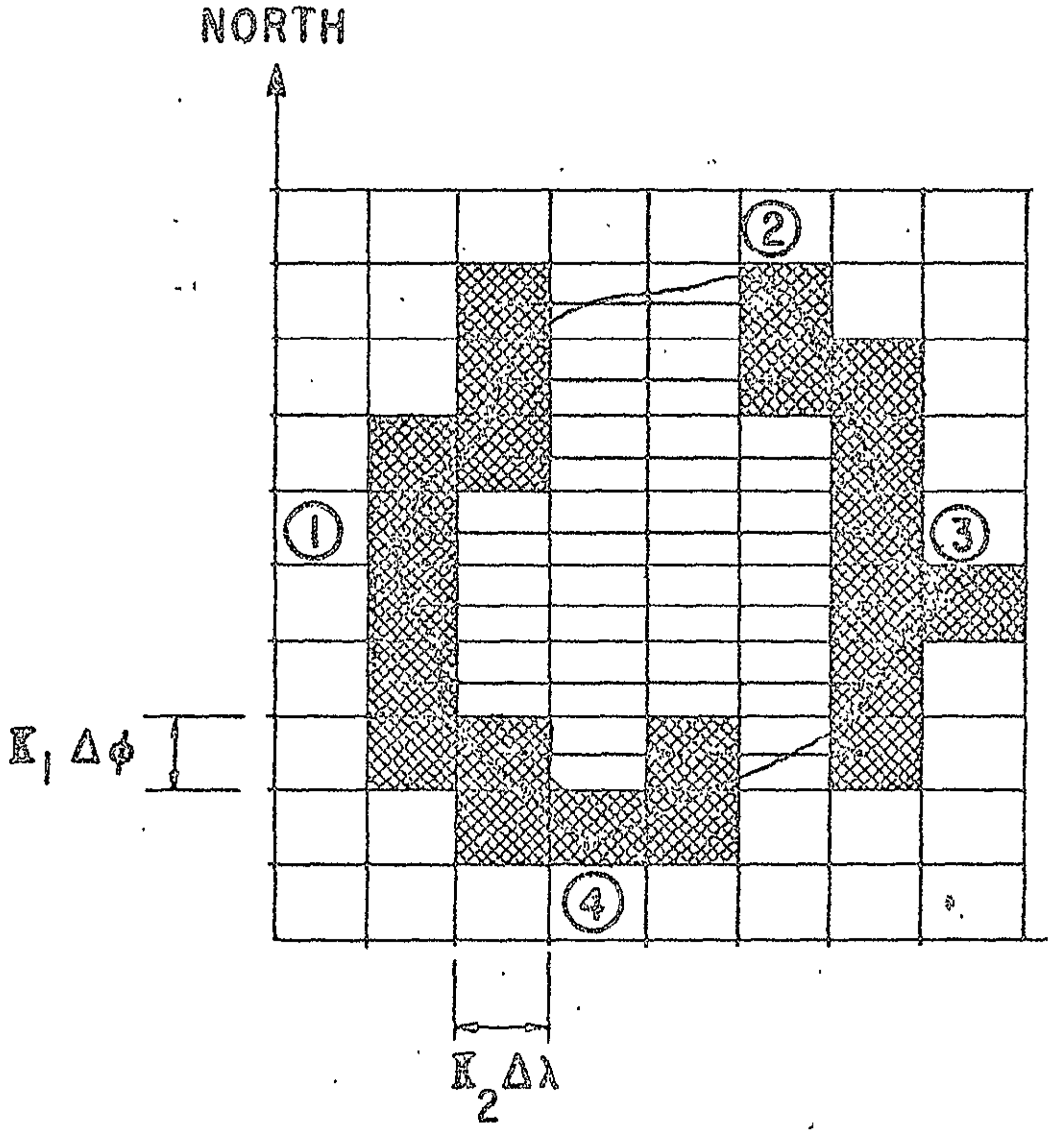
If image correlation has provided a measured transform from data coordinates to ground coordinates, the frame boundaries are likely to be found quite non-linear due to terrain relief. Then the perimeter cannot be defined by four corner points and considerably more values must be used to accurately compute bin coverage. Other than that, the computation could proceed normally. Figure 9-5 illustrates the idea.

9.2 INITIAL RETRIEVAL

In general, the processing system must be able to service both routine and special purpose requests. Members of the first type determine the high-volume production processing tasks, are based on a priori knowledge and decisions, and are posed in terms of ground coordinates or mission parameters. Special requests arise in review of mission data or in various analysis tasks; they can vary considerably in the amount and type of data involved and may be stated in image coordinates as well as in the other two forms. Part of the request is an instruction to retrieve certain data from mission and/or historical files and part of it indicates what is to be done with the gathered material. The latter part, in effect, initiates an entry into some portion of the normal flow. Of concern here is the first part, wherein the request must be serviced. The approach is to derive "Frame" numbers which control the data call-up.

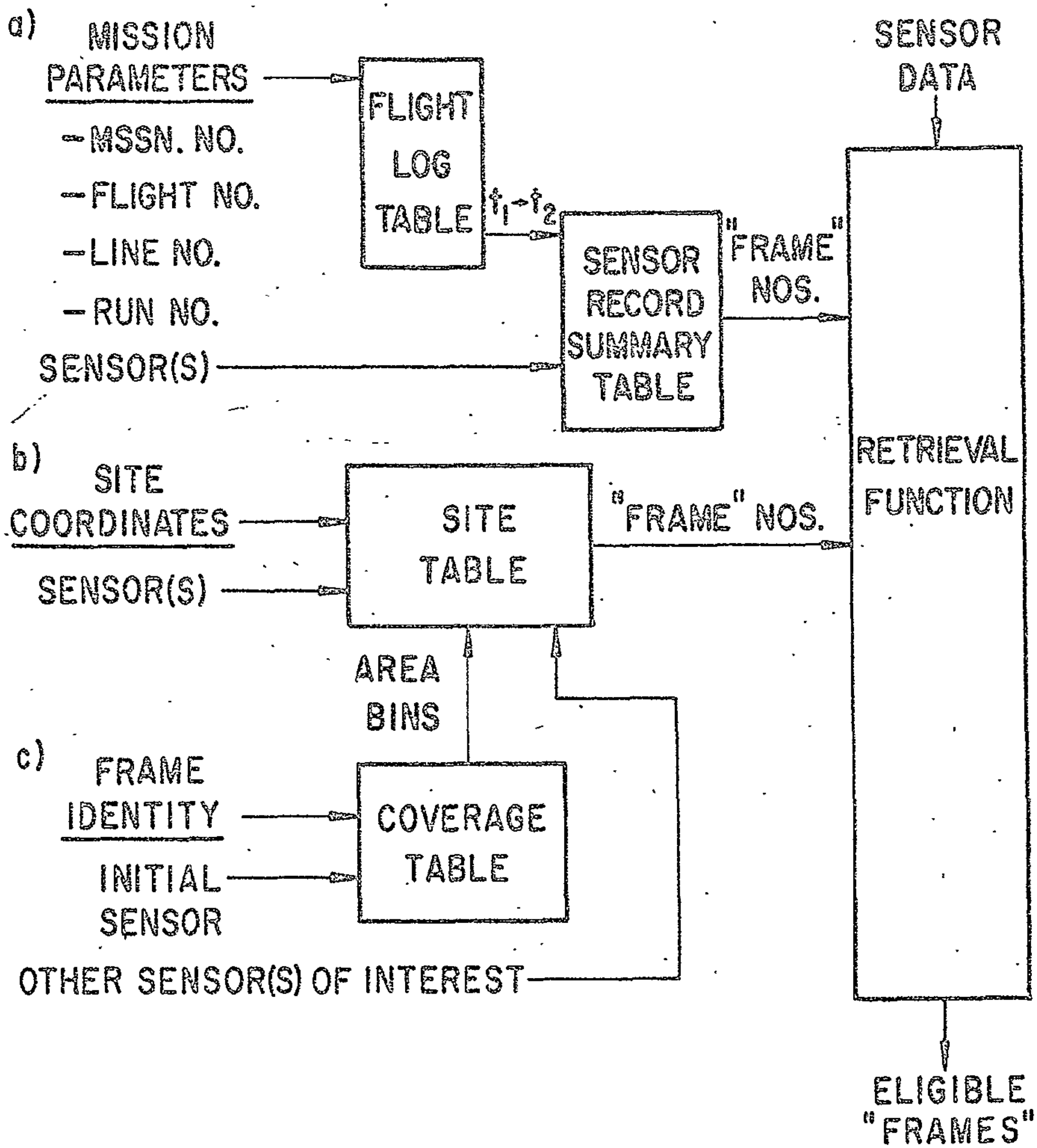
Depending on the given inputs, the retrieval procedure would follow one of the paths shown on Figure 9-6. It can be seen that, once the Index Files have been constructed, retrieval control reduces to a sequence of table look-ups.

Another necessary capability, not shown on the diagram, is the use of mission time as a retrieval control parameter. It may or may not appear as an explicit input instruction ("Call up all sensor N data from t_1 to t_2 "), but it exists as an implicit direct link between data sets and might advantageously be put to use. For example, an analyst might wish to review series of composite multispectral images on a false color viewer.



COVERAGE CALCULATIONS BASED ON IMAGE MEASUREMENTS

FIGURE 9-5.



RETRIEVAL PROCEDURES

FIGURE 9-6.

Time coincidence could provide a quick test for corresponding image frames on the different film rolls. Similarly, if he wished to compare, say, spectral band images from a camera and a point scanner, time coincidence could produce a more rapid retrieval than would be obtained by first interposing a conversion to Frame Numbers.

9.3 "CONVERSION" INSTRUCTIONS

The discussion to this point has centered on a method of data retrieval (based on derived frame numbers). Now it becomes necessary to examine the purpose of the retrieval. If the intent is merely to transfer selected "frames" to a display or to some output package, then no further computations are required. However, a major flow path at the output end of the ADCS leads to the Signature Analysis System, and that introduces some possible control options.

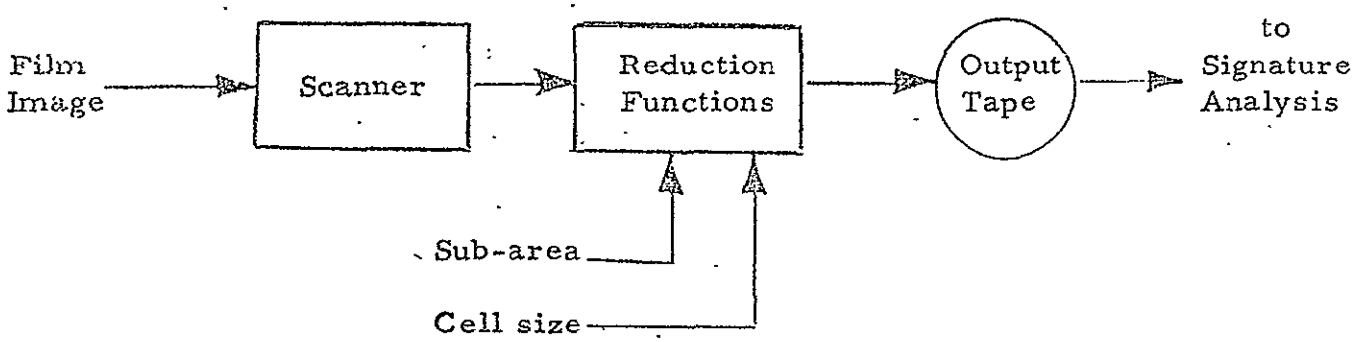
There are several ways that image data might be converted to forms suitable for signature processing. In the first place, fully processed frames might be retrieved and visually reviewed by an analyst and a selected group forwarded toward the Signature System, or the decisions might have been made anywhere in the prior flow and the routing here would be automatic. The analyst examination might involve false color viewing (not shown) and he might select whole frames or define partial areas of interest. Furthermore, depending on the tools at his disposal, he might designate partial areas in at least three distinct ways:

Specify ground coordinates;

Specify image coordinates which, in turn, might be used to demark an area sub-set within a fixed scan pattern (e.g., opto-mechanical film scanner);

Zoom, translate and rotate a multi-channel TV scan until the region of interest essentially fills a monitor screen, then route the video to a digitizer and, ultimately, to the Signature System.

The notion of using partial image areas is an extremely important one. If a 4.5 x 4.5 inch multispectral image format were scanned with a 1 mil spot, some 20 million readings would be accumulated per picture and a 4-picture set, for one scene, would entail 80 million samples to be analyzed in the Signature System. Clearly, this is prohibitive. And it is also clear that area reduction alone may not be adequate. It might be desirable to adjust the dimensions of the data "element" sent to the Signature System. And that might be done with certain limitations within the scanner hardware or more freely by hardware and/or software operations on the total scan data. The general flow would be:



Each of the possibilities mentioned, and any other that might eventually be conceived, directly shape the output flow path and indirectly impose demands for the availability of "conversion" instructions that can range from very general (frame number) to very specific (image sub-area and cell size). Nor are the identifiable variations yet exhausted. For example:

> Should cell size be in image dimensions or ground dimensions?
>
> Should a particular signature analysis task be conducted element-by-element or is it preferable to employ a "diminishing search" routine where only those cells which satisfy $D_1 (\lambda_1)$ are tested for $D_2 (\lambda_2)$, etc.?

The answer to both questions would appear to be, "It depends". But then two unexpected possibilities become real; viz., that highly specific data-ground correlation might be performed only <u>after</u> data-data Signature Analysis has discovered some item(s) of high interest and, secondly, that the data search could become a vital function <u>within</u> Signature Analysis.

Speculation of this sort will undoubtedly continue to expand and be gradually resolved as the overall system concept develops. For present purposes, it will be assumed that:

1) An analyst can route an entire viewed image or any part of it toward Signature Analysis;

2) He can designate a sub-area in either image coordinates or ground coordinates;

3) He can cause any data covering a specified image or ground area to be routed to Signature Analysis, whether he views it or not;

4) Registered tapes will be prepared which contain the per sensor spectral components for each element in the original area of search; "diminishing search" functions might be performed with those records but not with the initial sensor data;

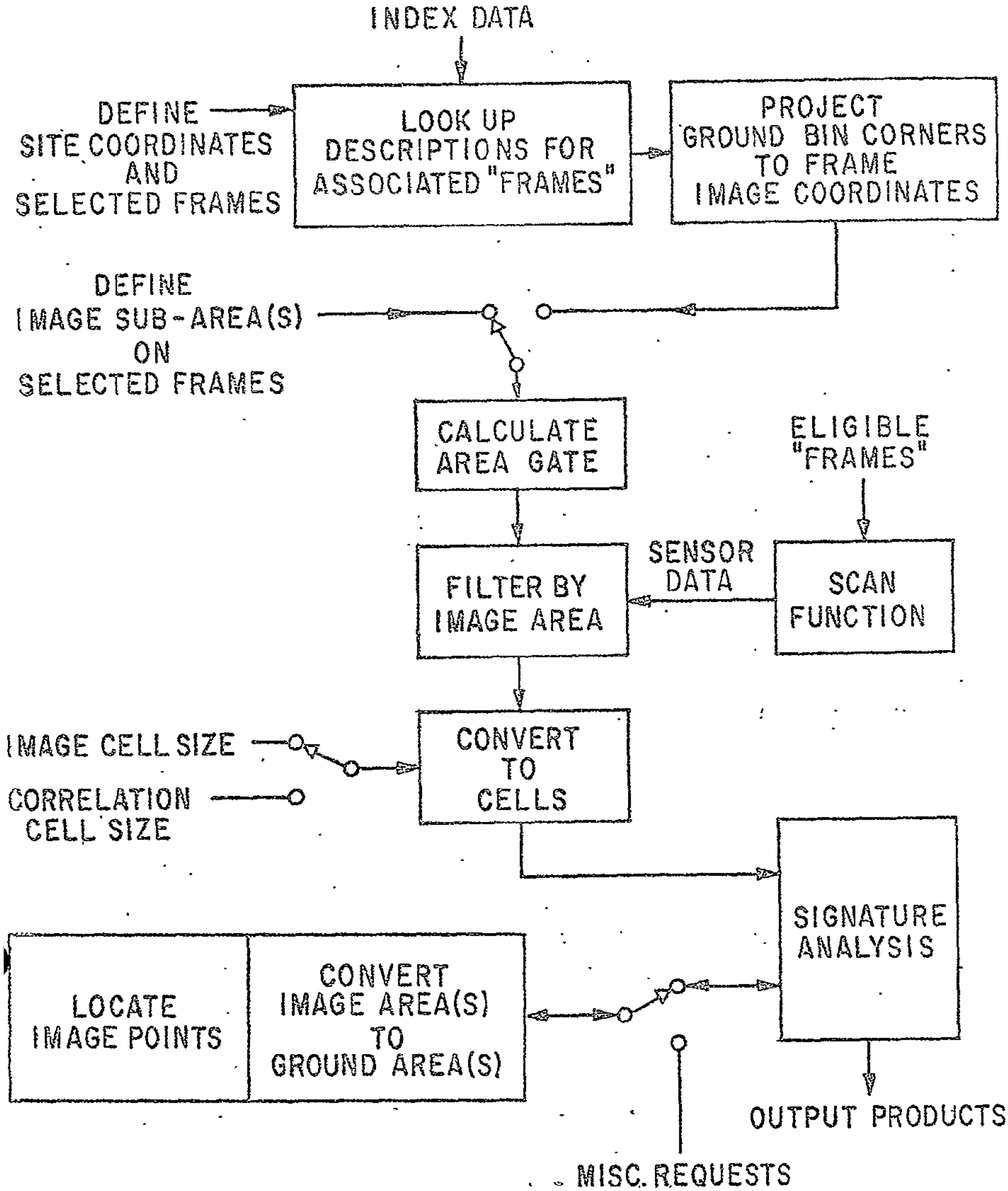
5) Tape elements can be transferred as is, or converted to uniformly spaced "image cells" or ground-coherent "correlation cells"; either type to be dimensioned arbitrarily;

6) Requests for ground locations of points or for conversion of image areas to ground areas may be serviced before or after Signature Analysis.

7) Conversion from ground area units to desired output units (acres, bushels, etc.) might be performed anywhere; since it is merely a scaling function it will not be further described here.

These statements are summarized in the partial flow diagram, Figure 9-7, and the conversion geometries are shown in Figure 9-8.

Note that the processing steps are quite similar to ones previously described for determining overlap between data frames and ground area bins.



CONVERSION OPTIONS

FIGURE 9-7.

The first calculation here (part (a) of Figure 9-7) would use arbitrarily sized image area bins to limit acceptable scanner data to that portion of the total set which is of interest. The derived control function is, in effect, an image area gate.

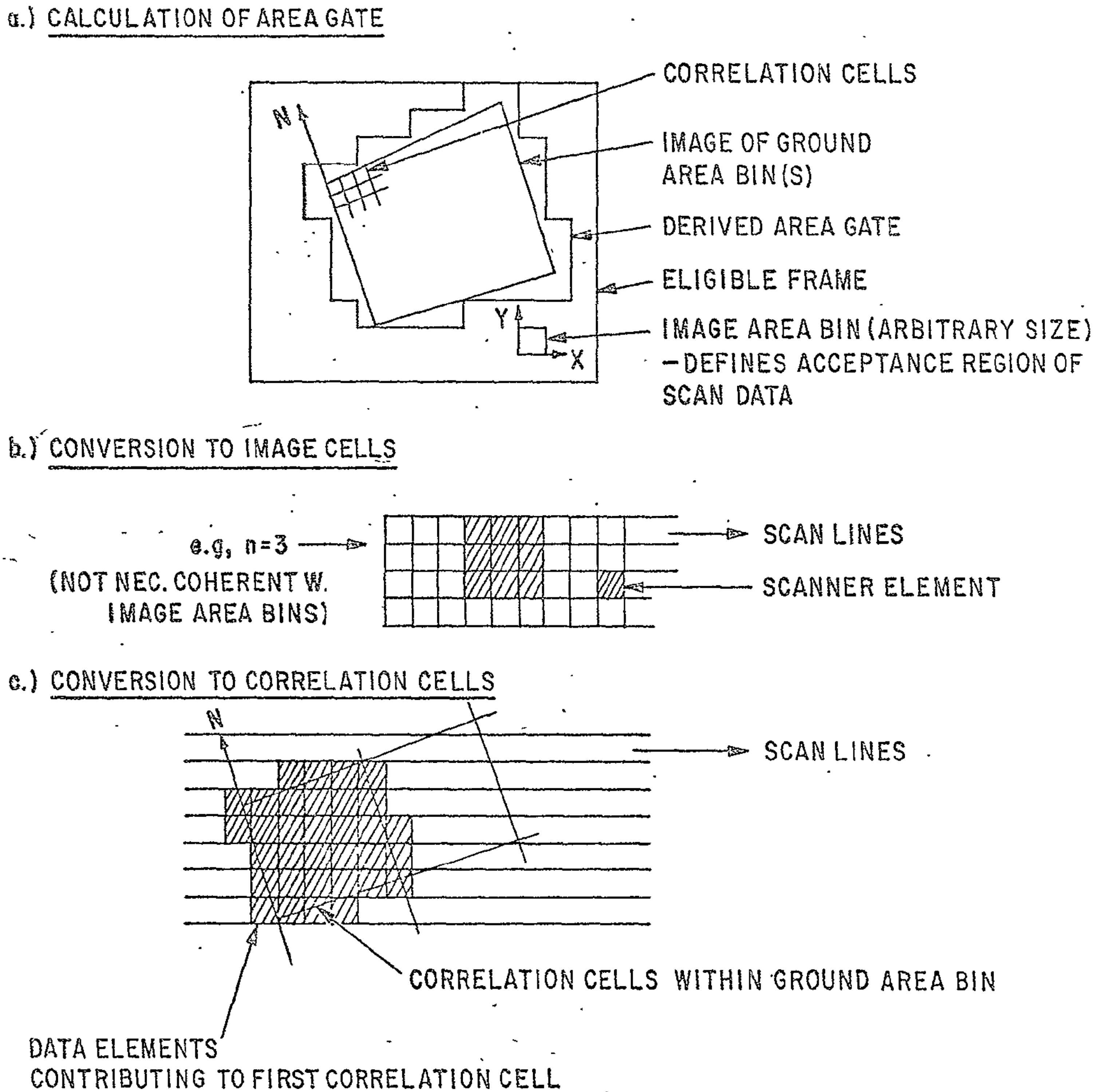
The initial step is to convert the corner coordinates of each included ground bin to appropriate image coordinates. This transform varies from frame to frame but all necessary relationships, measured or calculated, are available. Each ground bin forms a straight sided quadrilateral when projected to the image plane, so the computation of intersected and included image bins is identical to the earlier coverage calculations. The effects of terrain relief also could be handled as indicated in Section 9 or another layer of image bins might be added around the perimeter of the initial area gate to offset the fact that the true projection of the ground bin would not be straight sided.

The adoption of image bins is merely a contrivance which allows simple count gating, and hence area "filtering", of scanner data. Bins are aligned with the image X and Y axes, as is the scanner, but since the selection function is a gross one, it is not necessary that calculated image bins and actual scan elements be repeatably registered with one another.

Once the scan data has been collected, conversion to image cells is very direct. The scan elements per cell are merely accumulated and averaged (at uniform or distributed weights), so a single new value for and n x n cell replaces n^2 scan elements at the output.

This will probably be the normal flow to the Signature System except that the analyst might frequently choose to examine arbitrary image regions. Assume he does the equivalent of spotting corner coordinates of quadrilateral sub-area(s) within any image in view. Then the computation begins with the derivation of the area gate. Even that calculation can be by-passed if the analyst uses aligned cross-hairs, or the like, to specify the gate directly.

If it is expedient to reduce sensor data to ground correlation cells, the geometry in part (c) of Figure 9-8 obtains. Note that image data scanning, whether from photographic film or magnetic tape, can be considered as another gridding process where the pixels or data elements from a "frame" are geometrically aligned in a rectangular array.



CONVERSION GEOMETRIES

FIGURE 9-8.

Since the data coordinates of both the correlation cells and the smaller scan elements are known, the same calculation routine could now be used a third time to define the data elements per correlation cell. However, a simpler procedure should probably be used initially. See Section 9.5.

. All "conversion" computations are now complete and the control information can be tabulated and filed for later reference.

Image-to-ground conversions after Signature Analysis are merely repetitions of functions already described.

9.4 SELECTIVE DATA SCANNING

The extraction of selected sub-sets from various input records may involve many sensor collections and they may be recorded on any of the storage media available-color or black and white photographic film, digital magnetic tape and/or analog magnetic tape.

Portions of digital tapes can be read into a digital interim storage directly; analog tape readings must be A/D - converted; film images must be optically scanned and the analog output signal digitized. In each case, the reading from initial storage will provide more information than the specific detail requested. The trimming to final values could entail reductions by:

Ground or image area limiting

Spectral separation

Signal amplitude slicing

All of these data filtering operations could be performed by software routines or they could be hardware functions. The first one requires special purpose hardware; the second is automatically available on tape records and easily incorporated in a (color) film scanner; the third could be developed as a simple module that would operate on digital values from any source.

After the data have been scanned out of their initial records and culled, each set must be sorted according to image or correlation cell geometry, converted to composite per-cell values, and formatted on 1108 CCT for Signature Processing.

The same selection procedure, with or without the data adjustments, can also be used to retrieve other output products directly.

9.5 CONVERSION TO CORRELATION CELL VALUES

The conversion from data elements to "appropriate" correlation cell values is obscured by the random geometric relationship between sensor footprints and the reference ground grid. The problem would vanish if all sensor collections could readily be described in terms of perfectly registered multiples or sub-multiples of the grid cells. But since sensor ground intercepts vary in size, shape and orientation, no such convenient arrangement exists. Hence, processing rules are needed.

The final version of these rules will develop as data analysts study the effects of possible variations on signature processing. Both geometric and radiometric adjustments are involved but the central issues are how to treat partial overlaps between elements and cells, whether or not to apply weighting factors to elements distributed over a larger cell, and how much significance to attribute to spot shape.

Until such time as a preferred scheme is defined, the simplest approach might be assumed as a tentative "best" one. A reasonable policy might be as follows:

1) When data elements are considerably smaller than a cell, assume they are point samples rather than miniature areas. Then only points within a cell contribute to the net cell value; points that fall on grid lines can be considered to lie in both (or all 4) adjacent cells. It is immaterial whether the given address of a data element corresponds to the center of the element or to some location on its periphery, provided the relationship is fixed for a given set of inputs.

2) When data elements are in the same size range or larger than cells, assume they can be approximated by rectangular areas. All cells that completely or partially fall within a rectangle are assigned the value of the corresponding data; if rectangles overlap, some cells will accumulate two or more data values.

3) The net cell value is assumed to be the unweighted average of all values assigned to the cell.

Figure 9-9 illustrates the situation geometry for two representative cases, scanned film imagery and a tilted profile sensor. It seems unlikely any application will have much use for sensor data having a ground resolution considerably poorer than the desired cell size, so that possibility is not shown.

Under the stated assumptions, the calculation of cell values is fairly straightforward. Point assignments involve merely address sorting and area computations can again use the same routine as employed in earlier constructions.

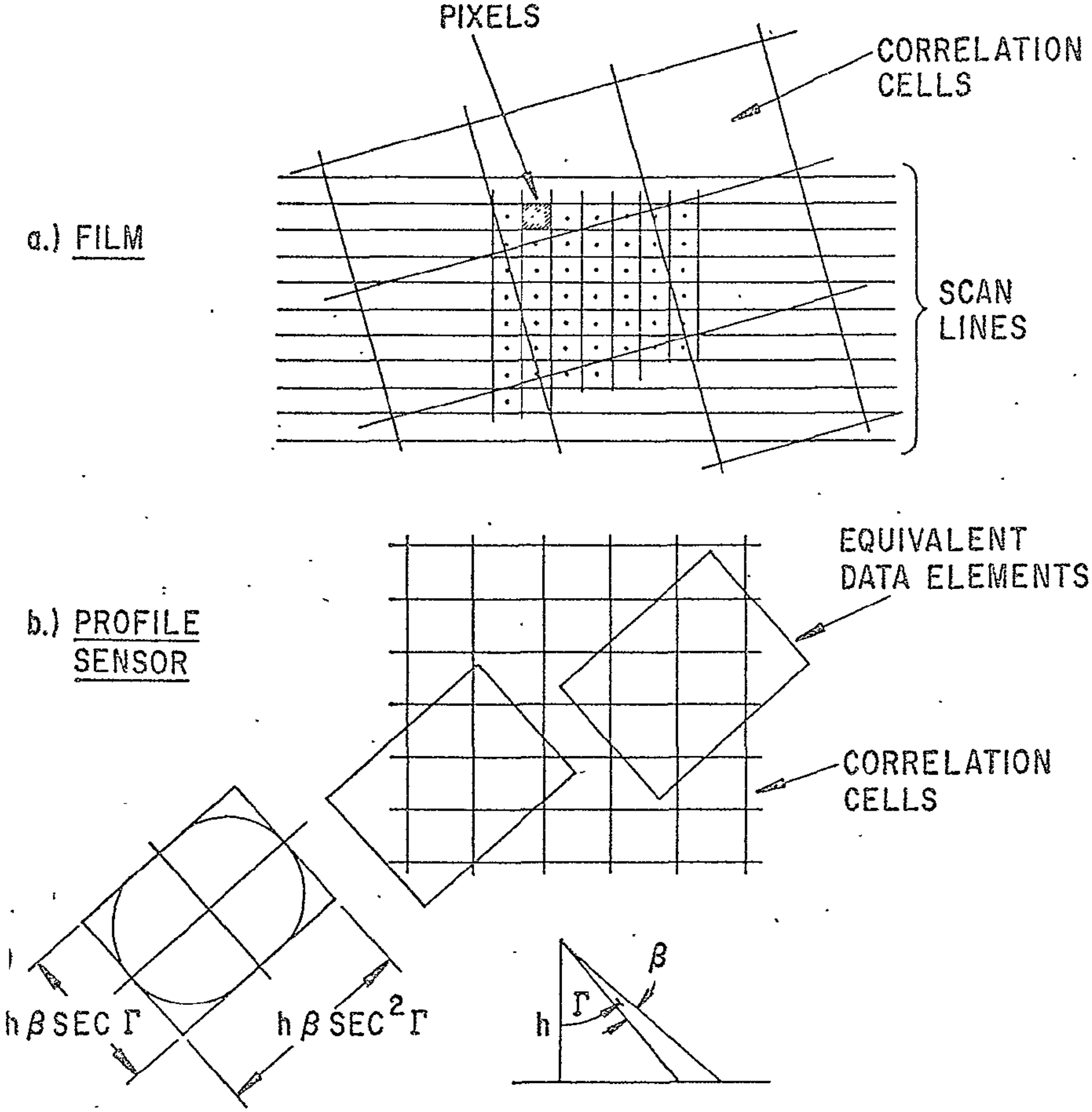
9.6 SIGNATURE SYSTEM INTERFACE

If the preceding discussion was anywhere near the mark in projecting desirable system output functions, then the interface between the ADCS and the Signature Analysis System will be fairly complex. At the very least, it appears that it should be a flexibly interactive link rather than a one-way data spout. From a broader view, these major subsystems are merely components of a larger, integrated whole with indistinct inner boundaries. However, that topic is beyond the scope of the present study.

To summarize what has been suggested, insofar as it directly affects the current understanding of "interface", the ADCS should be able to:

1) Accept and respond to processing requests and control instructions from the signature system as well as from internal sources;

2) Provide output sensor data on 1108 CCT that has been formatted in at least two ways- collected spectral signatures per geometirc element or successive element values per spectral band;



CONVERSION FROM DATA ELEMENTS TO CORRELATION CELLS

FIGURE 9-9.

3) Provide whatever auxiliary output data is requested (e.g., data ground coordinate transforms, ground area measurements, etc.)

These features must be specified quite carefully in a detailed system design study.

9.7 SYMBOL OVERLAYS

A limitation of all non-imaging profile sensors is that the ground coverage is not readily apparent. There is no broad area picture to orient the analyst or present a synoptic view of the ground intercept trail. As a result, it becomes a tedious and time-consuming chore to determine which objects on the ground gave rise to particular responses from the sensor. Fortunately, the condition can be remedied easily.

An exact solution could be obtained if perfectly aligned boresight photographs were available for each profile device. Then image correlation techniques could be used to locate boresight photo principal points on mapping camera frames. The latter would provide the area context and the point history would denote the ground intercept of the sensor.

But boresight cameras are not perfectly aligned, particularly if obliged to track the sensor over an adjustable tilt angle, and the intercept of interest might be somewhere off axis. In scatterometer data analysis, for example, it might be desirable to plot the intercept histories and sensor output fluctuations for specific look angles. Therefore, computer methods seem preferable.

Experiments have already been performed, using the NASA/MSC Earth Resources P3A aircraft, to determine the accuracy of ground intercept calculations. Eppler (Ref. 5) reports:

"It was found that the RMS errors between the computed and actual boresight positions were less than 0.25 deg. referred to the sensor.... these errors are comparable to or smaller than the beamwidths of most non-imaging sensors used currently. On this basis it appears that overlays... prepared using existing instrumentation and methods are sufficiently accurate to aid in the correlation and analysis of remote sensor data".

The only comment to be added here is that the generation of symbol and signal overlays for this purpose should become a standard function which is normally exercised in the production processing flow. It might be particularly useful if color contrast were employed to enhance symbol visibility.

Figure 9-10 is a sample of the signal overlay work currently being done at MSC. It clearly illustrates the merits of the technique.

9.8 MISSION PERFORMANCE

It is, of course, a truism that all data gathering missions ought to be throroughly evaluated in order to assure the on-going success of the Earth Resources Program. The advent of an extensive data processing/ analysis facility means that, for the first time, it will be possible to assay mission performance both quickly and comprehensively.

Factors to be weighed comprise four major categories:

- Satisfaction of mission objectives
- Prime sensor equipment performance
- Auxiliary equipment performance
- Vehicle/crew performance

Mission objectives include sensor coverage and statements relating to the purpose of the collection. Detailed ground area coverage could be computed and compared to the intended coverage but it would be far simpler, and probably as effective, to compare flight log data with planned runs. Satisfaction of purpose can be judged only after all data has been at least partially analyzed.

Prime sensor equipment, auxiliary equipment and vehicle performance can be tested for gross effects during the mission, and crew procedure can also be evaluated without machine assistance. However, the comments should be entered into the Management System in order to compile a performance summary report and assist in analyzing the end-to-end operation.

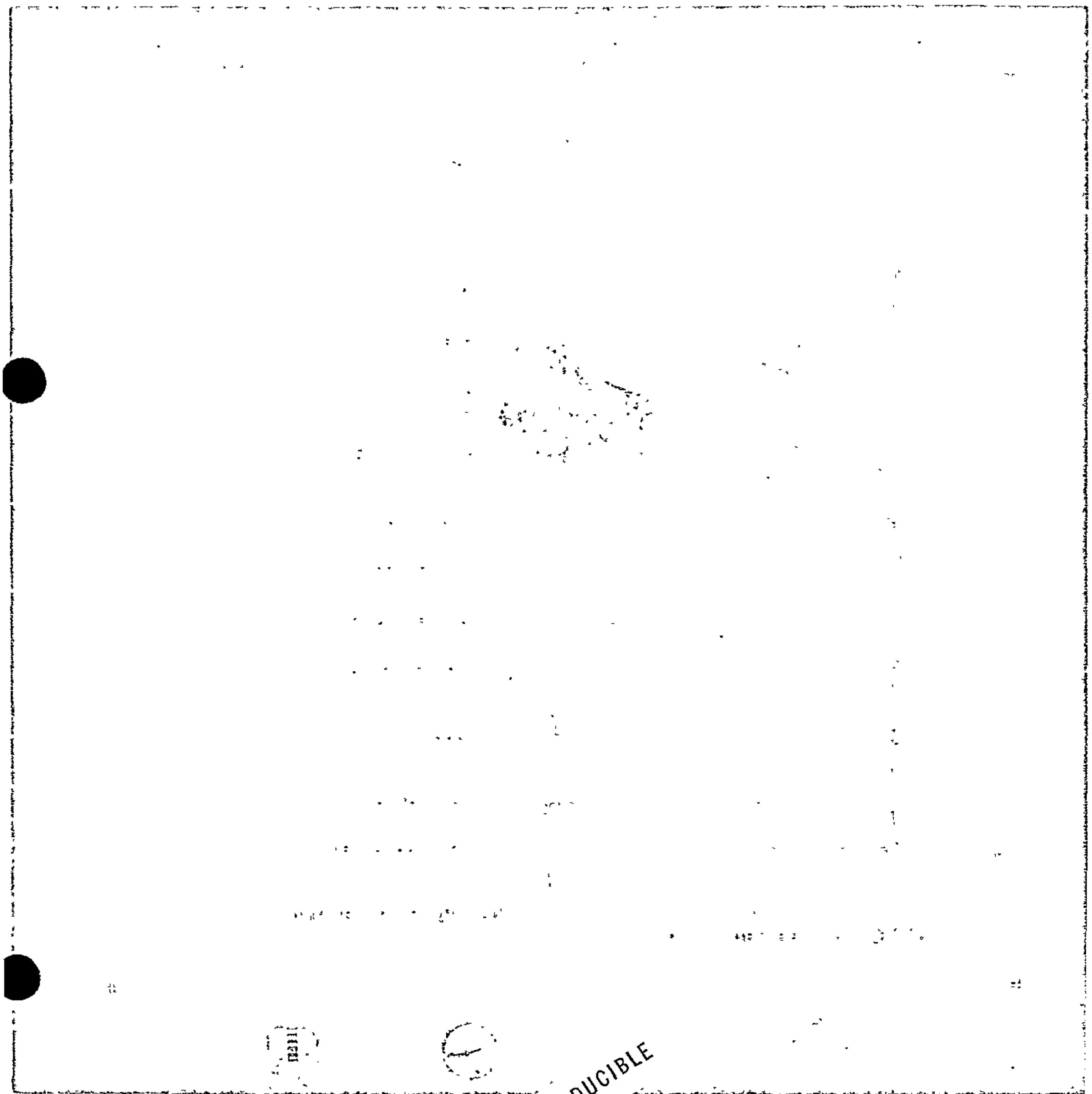


FIGURE 9-10. SIGNAL OVERLAY

Some equipment malfunctions may be not at all evident without very detailed cross checks. NAV data is one such example. All data readings can be tested for intermittent failures and out-of-range conditions, and it was indicated that this ought to be part of the routine Preprocessing operations. Gyro drift can also be detected there by checking against flight log entries. And now, at the output end of the processing stream, where ground correlated imagery is available, other tests can be made. Figure 9-11 indicates how imagery can be used to spot check value readings of ground speed, altitude, pitch, roll, heading and yaw.

Prime sensor data might be validated by statistical checks or cross reference tests if suitable ones can be devised. The corresponding error messages and analyst comments would be summarized with other similar inputs.

9.9 MISSION PACKAGE

Those ADCS processing products which are not sent to the Signature Analysis System should be compiled into a mission "package" and delivered to the Central Data Bank for eventual dissemination and analysis. Data may be on any recording media available and in whatever formats are found to be most useful.

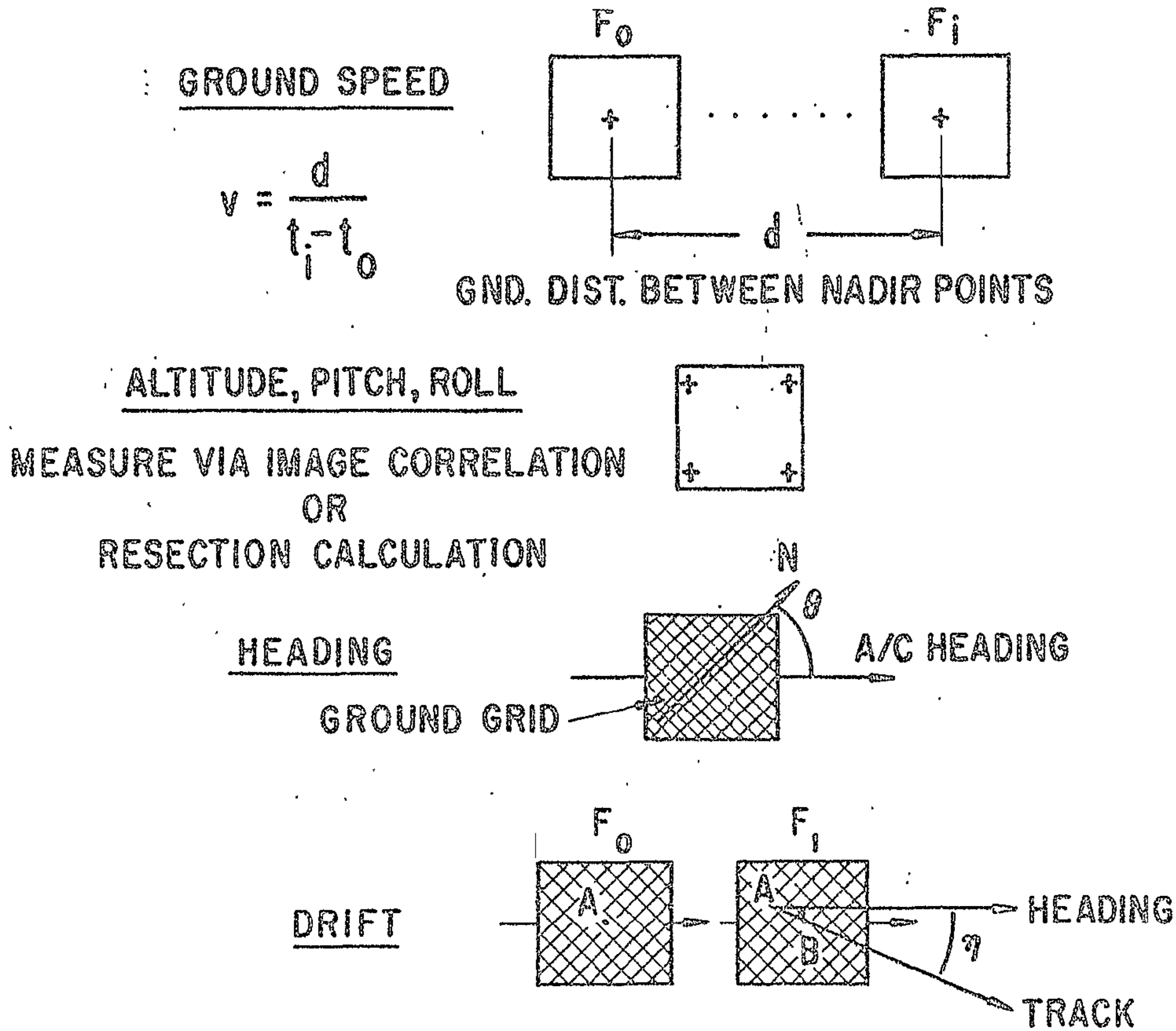


IMAGE CHECKS ON NAV DATA

FIGURE 9-11.

SECTION 10

LIBRARY FUNCTIONS

FOREWORD

The preceding section dealt with the last major topics within the formal purview of the ADCS study. However, as in all large-scale conceptual designs, there was an abiding necessity to project some reasonable structure onto the surround in order to "assure" the end-to-end workability of the larger operation. The point was made under SYSTEM PHILOSOPHY and some specific remarks were introduced under COLLECTION CONTROL. This section is essentially an epilogue which concludes the overview discussion with a few comments on Library Functions.

Figure i presents the assumed general configuration. Not shown are the equally vital management and special purpose offices. These are discussed in Reference 1 of the Bibliography and will not be examined here.

SECTION 10 CONTENTS

10.1 SERVICE CENTER

The underlying theme of the entire facility design should be the idea of making it as useful as possible to the people being serviced. This implies a high degree of flexible automation at the user interface and fairly simple retrieval procedures. A newcomer should be able to learn to use the system in a few hours and requests should not entail the filling in of pages and pages of forms. In short, access to the system must not be a burdensome task.

It seems valid to assume that a Service Center within the Library will be responsible for all activities relating to interfacing with the user community. Then it must have access to the Data Bank, to printing and publishing facilities and to dissemination services (TWX, facsimile, etc.) It is a safe guess that some users will want to work at the processing center while others will prefer that data products, information and, possibly, recommendations be routinely sent out to them. Still another class is likely to find time-shared remote access via telephone link a desirable feature. That could get enormously complicated if they were able to remotely browse through the files, extract data of interest and cause it to be processed in several ways. One can envision a Data Exchange interacting with the processing Management System to regulate a vast and complex data traffic.

A flow of instructions and requests would also have to be organized and controlled. If spacecraft collections are eventually coordinated in the same facility, then links must be established to all pertinent Mission Control Centers and collection stations.

Presumably, the Service Center would provide a number of displays for casual users but they might be designed to assist in the search for high interest data rather than in its analysis. A likely possibility is the use of desk top television displays. These would allow high speed, medium quality image data screening and unlimited computer readouts. An associated keyboard and possibly other conventional controls (light pen, etc.) would permit a complete freedom of operator entries. Assuming suitable "soft" controls (i.e., step by step options presented on the CRT screen rather than hardware function keys), an operator would be able to hunt through all relevant

sections of the data bank, automatically compile a list of descriptions identifying the items of interest, and request that specific follow-on tasks be performed (retrieve-copy-process-output).

He might then move over to an Analysis Center for a more thorough examination of the requested data.

10.2 ANALYSIS CENTER

Just as the Service Center is needed for overall traffic control, so too is there a need for an Analysis Center to direct the detail processing steps, provide the tools for conducting in-depth scientific investigations, and assist in various planning activities. Six different kinds of tasks can be identified immediately:

1) Mission Planning
2) Production Scheduling
3) Mission Analysis
4) Area Analysis
5) Topic Analysis
6) Long Range Planning

Tables 10 - 1 through 10-6 list some of the considerations which can be expected to pertain in each of these categories. The intent is merely to note the types of requirements which could arise, so the lists are by no means complete. Since this report is focused on the ADCS study, it was felt appropriate to examine "Mission Analysis" more closely than the other five Analysis Center tasks, so Table 10-3 is relatively long.

Equipments in the Analysis Center should include at least the following:

- Closed circuit television consoles
- Single-channel film viewers
- Multi-spectral false color viewers
- X-Y Plotters
- Microfilm Plotters
- Computer-driven graphic and alphanumeric displays
- Standard computer peripheral devices

A reading of these functions and equipments underscores again the need for a very extensive and capable software management system. It is strongly recommended that provision be made for a continuing R&D effort along that line as the total system evolves. A few final observations also bear on that problem.

10.3 FINAL OUTPUTS

A pitfall in designing a system that is to accommodate a wide variety of users, each bent on deriving different information, is the tendency to allow as many processing options as possible. This is particularly true in the early stages, when predicted needs are very vague. The idea, of course, is to preseve flexibility in order to guarantee that "usefulness" mentioned earlier. But it can be overdone, in which case the inevitable net result is unnecessary complexity and its concomitants-degraded reliability and higher cost. It can also be done in a "tack on" fashion, with much the same results.

Hence, some caution must be exercised in attempting to determine the users' real needs, and common factors should be sought out. In view of what is already known it seems reasonable to expect that the basic data products required might be very few, principally sensor data and derived plots, histograms, thematic maps, and reports.

Moreover, the processing functions needed appear to be roughly limited to those described elsewhere in this report, and the control instructions reduce to a very few:

1) Here is a ground (or image) area of interest. Put out:
   - all the data taken with sensor(s) N in that region
   - all the data taken with sensor(s) N, adjusted for cell size C
   - the spectral signature for any or all cells
   - the location of all cells containing item X

2) Here is an area of interest. What is the amount of item X it contains?

- acres
- yield, % of total crop
- level of maturity, health status
- moisture content/boundary, snow levels
- pollution levels, types
- geologic content
- soil richness
- etc.

3) Process the data according to the specified functions
- as indicated in this report

4) Are there any alarm conditions to be noted?
- emergency flags
- equipment malfunctions

So it might turn out that the number of fundamental mechanisms required are quite low in number, in spite of the potentially vast user community. That would indeed be a significant discovery. At the moment, however, it is merely an unvalidated suspicion. Hence, it is recommended that a user survey and analysis be undertaken as soon as possible.

TABLE 10-1

MISSION PLANNING FUNCTIONS

1. Examine user requests
   - date of application
   - type of data needed
   - special conditions
   - site location

2. Check status of
   - vehicles
   - sensors
   - crews
   - ground teams
   - other coverage sources

3. Check related experiments already planned or previously conducted.

4. Assign mission parameters

5. File a MISSION PLAN in the appropriate distribution channel.

TABLE 10-2

PRODUCTION SCHEDULING FUNCTIONS

1. Review the mission plan
   - type of data
   - volume
   - desired availability
2. Check the anticipated system status at the expected arrival time of mission data
   - loading
   - equipment state
   - flow rates
3. Schedule the processing
4. Alert the mission analyst

TABLE 10-3

MISSION ANALYSIS FUNCTIONS

1. Screen incoming data and define the specific processing plan.

2. Review the initial processing products.

3. Resolve ambiguities, where possible, by requesting and examining additional information such as:

   a) Actual signature obtained and reference signature used. The system might be unable to establish the

      - IDENTITY of an item
      - CONDITION of an item
      - CAUSE OF THE CONDITION (e.g., type of blight)

   b) An identical re-processing with a different

      - cell size
      - reference signature
      - sensor
      - data range
      - tolerance on the signal level range in one or more spectral bands

   c) Comparison of signal levels for particular spectral band(s) from different sensors

d) Previously derived signatures

- in same area
- in any area corresponding to the item of interest

e) Magnified photograph (beyond the display capability)

f) False color presentations

g) Scatterometer profiles using different

- doppler frequency bins
- reference criteria for a "signature" call

4. Request new processing products, because of something unexpected which catches the analyst's attention, or because of a last minute additional request, etc.

5. Respond to automatic EMERGENCY flags and, possibly, estimate the status of the crisis:

- agricultural blight
- red tide
- iceberg
- forest fire
- tsunami
- etc.

6. Update the "Real Time Monitoring" file (assuming one exists).

- blight growth (intensity, spread)
- motion of icebergs
- spread of forest fires
- etc.

7. Route appropriate photographs and other data into various Topic files and Area files.

8. Route appropriate data samples into Sensor Evaluation files.

9. Review and check any automatic "Recommendations" that the system might generate.

10. Tag all UNUSUAL ITEMS for further analysis

11. Generate a MISSION SUMMARY Report

    - tag all cases of missing data or incomplete objectives.

TABLE 10-4

AREA ANALYSIS FUNCTIONS

1. Analyze site characteristics by examining current and historical data, auxiliary reports and reference files. The latter should include summaries of what is and is not known about the site, conditions subject to change, projected events, etc.

2. Typical area studies:
   - Agricultural yield/controls/potential
   - Geological characteristics
   - Mineral surveys
   - Post-calamity damage assessment
   - Traffic flow
   - Cultural development

3. Generate Area Reports

TABLE 10-5

TOPIC ANALYSIS FUNCTIONS

1. Review characteristics and trends by examining specific files established to facilitate such tasks. Ground areas may be very large and time history data from several/many regions might be compared in order to analyze the phenomenon in greater depth.

2. Typical topic studies:

   - Ocean currents
   - Fish migrations
   - Precipitation cycles
   - Spread of snow line
   - Signature analysis
   - Sensor evaluation
   - Unusual items

3. Generate Topic Reports

TABLE 10-6

LONG RANGE PLANNING FUNCTIONS

1. Review

   - trends in user requests (type, discipline, area)
   - satisfaction with past results
   - technology developments
   - vehicle utilization
   - processing evolution
   - funding projections
   - program publicity and educational policies
   - existing plans and suggestions

2. Generate new plans and distribute to appropriate personnel and agencies.

APPENDIX A

COORDINATE SYSTEM TRANSFORMS

FOREWORD

Appendix A presents the derivation of the transform equations needed to convert remote sensor data coordinates into local and geographic ground coordinates. For convenience, a matrix notation is employed and all transforms are expressed in those terms. Conversion to lengthier forms, expressed directly in measured parameters, is straightforward.

APPENDIX A CONTENTS

APPENDIX A CONTENTS (cont.)

ILLUSTRATIONS | PAGE

A.1 NOTATION

The notational scheme used herein can be defined by examining the simple coordinate rotation shown in Figure A-1. The transform equation for the "positive" rotation through an angle α is:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}$$

or

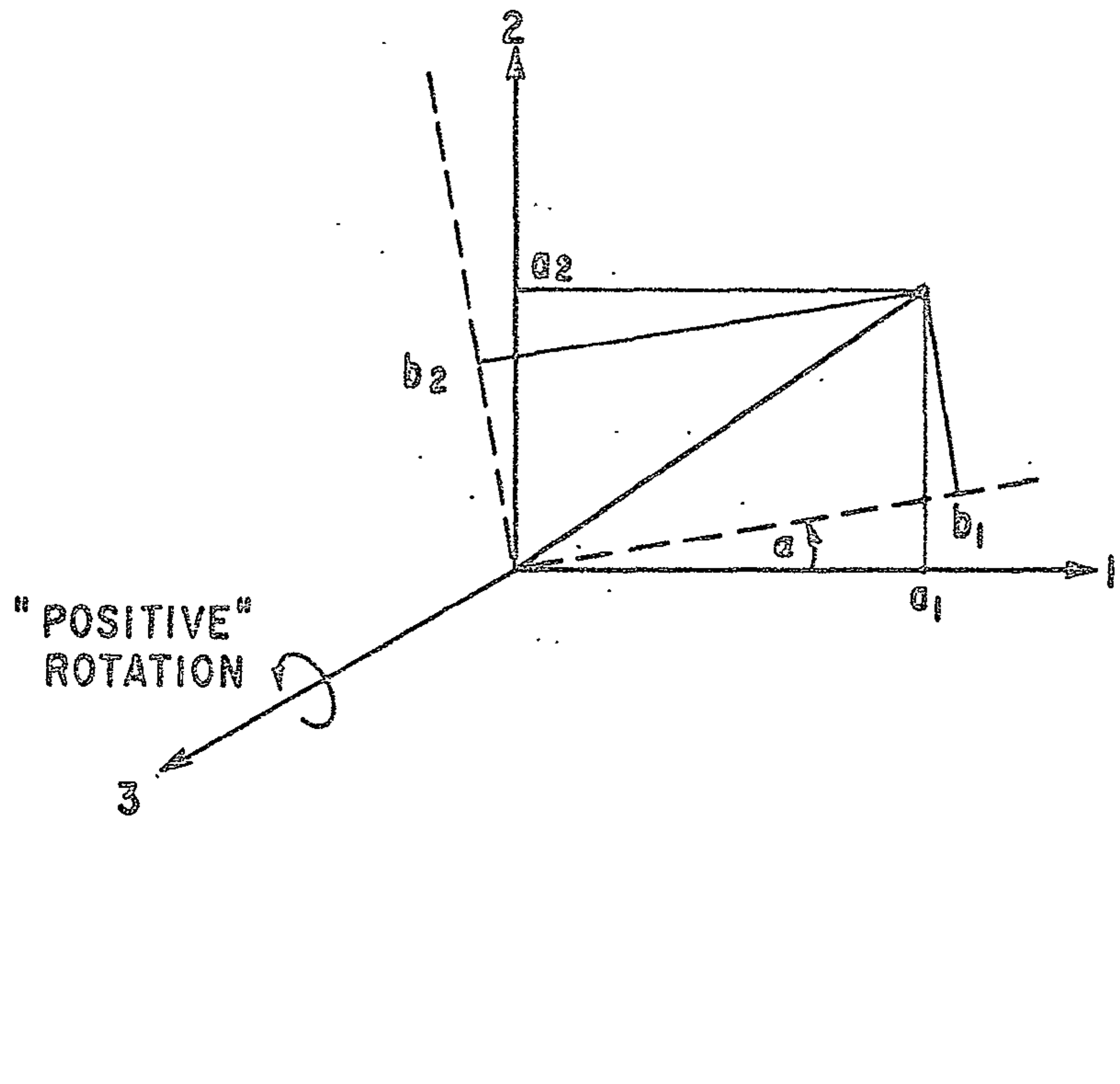
$$A = R_{ab} B \tag{A-1}$$

Similarly, for a "negative" rotation through a positive angle α,

$$R_{ab} = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

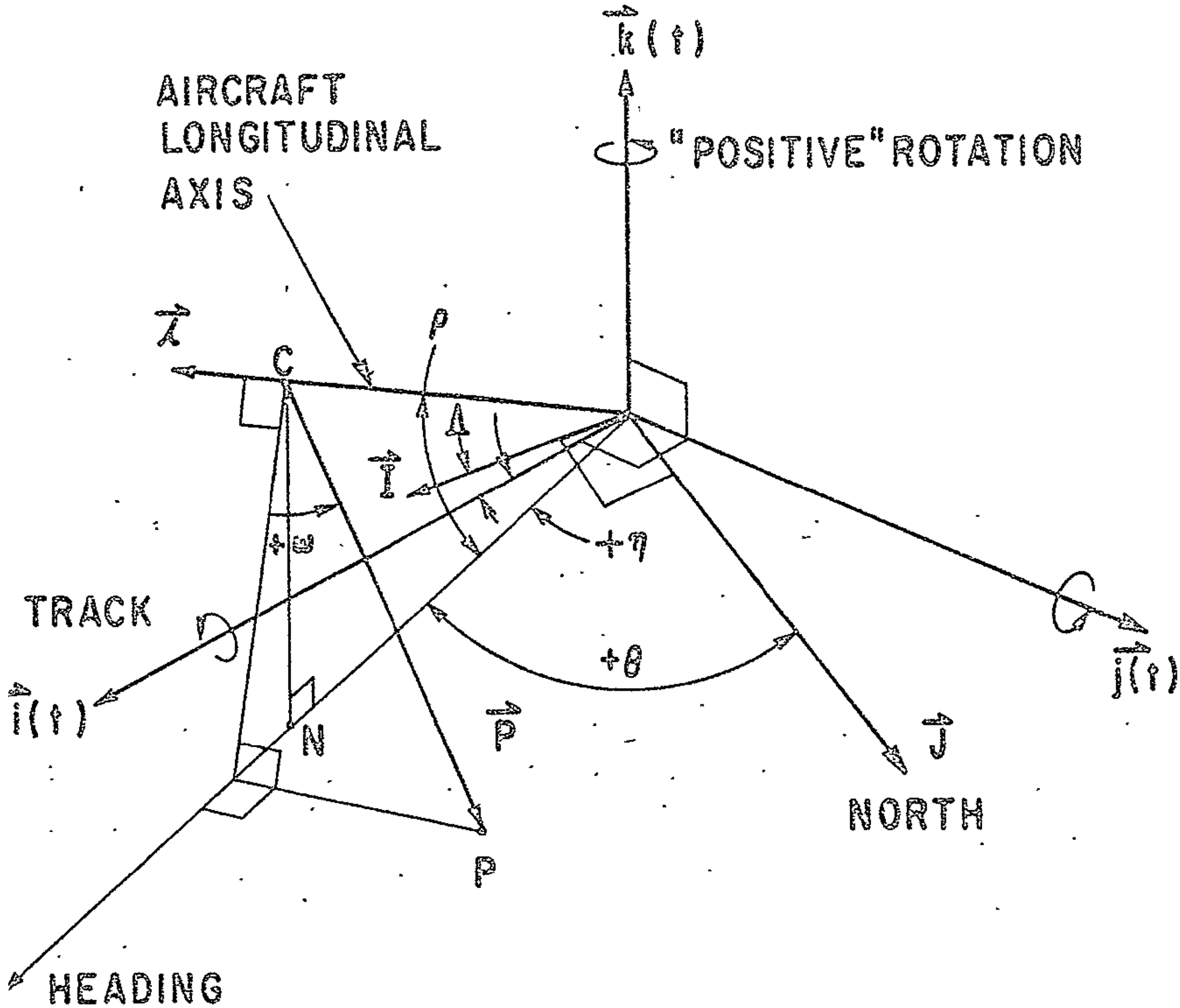
This is, of course, identical to a positive rotation through a negative angle.

Now consider the composite situation shown in Figure A-2. The aircraft (or, in general, the sensor platform) has a simultaneous angular displacement of:



NOTATION

FIGURE A-1.



ANGULAR RELATIONSHIPS

FIGURE A-2.

Roll .... $+\omega$ degrees

Pitch .... $+\rho$ degrees

Drift .... $+\eta$ degrees

Heading .... $+\theta$ degrees

Since all angles are varying with time, define the instantaneous right-hand coordinate system shown, i.e.:

$$\vec{i}\,(t), \quad \vec{j}\,(t), \quad \vec{k}\,(t)$$

where k is always vertical, so $\vec{i}$ and $\vec{j}$ lie in a horizontal plane and "positive" angles are defined as shown.

Let a non-rotating reference system (but one which translates with vehicle motion) be defined by $\vec{i}_o$, $\vec{j}_o$, $\vec{k}_o$ under the "zero" conditions given in Figure A-3.

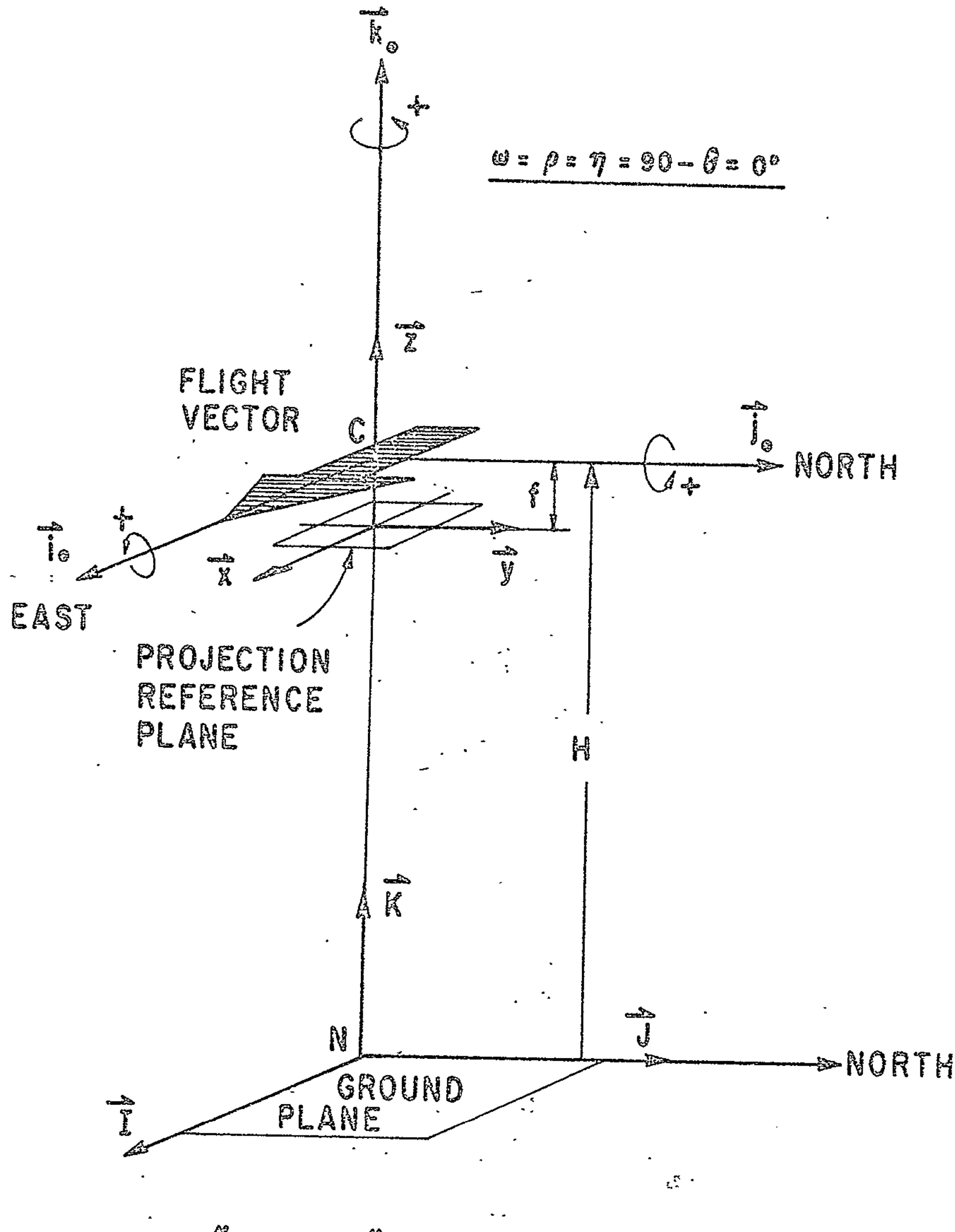
Then the composite attitude of Figure A-2 can be described by a sequence of rotations beginning with the "zero" state:

1) Roll $+\omega°$ by a positive rotation about $\vec{i}_o$

2) Pitch $+\rho°$ by a negative rotation about $\vec{j}_o$

3) Adjust heading through $(90 - \theta)°$ by a positive rotation about $\vec{k}_o$

Note that yaw angle, η, does not enter into these operations. The underlying assumption is that all sensors are hard-mounted to the aircraft or are on platforms which are not yaw-compensated. If the converse is true, the last correct becomes:



"ZERO" CONDITIONS

FIGURE A-3.

3A) Adjust track through $(90 - \theta - \eta)°$ by a positive rotation about $\vec{k}_o$

The total transformation from aircraft coordinates to some fixed ground system can be performed in five steps:

- Rotation into a local reference ground system
- Correction for earth's curvature and atmospheric refraction
- Transformation from corrected local ground coordinates to geocentric coordinates (X, Y, Z)
- Transformation from geocentric to geographic coordinates
- Transformation from geographic coordinates to desired base system (UTM, Lambert Conformal, etc.)

In addition, it is necessary to be able to convert the final values to plotter coordinates.

A.2 GENERATION OF LOCAL GROUND COORDINATES

Each major type of sensor has a different equation for determining the local ground coordinates from the sensor data point. It is convenient to develop the relationships in the following sequence:

- Frame photography
- Profile sensors
- Panoramic photography
- SLAR
- Point scanners
- Push-broom imagers
- TV sensors

A.2.1 Frame Photography

Let the system ($\vec{x}$, $\vec{y}$, $\vec{z}$) in Figure A-3 vary with aircraft attitude and position. It is assumed that the origin, C, (the optical node) is located at the vehicle center of rotation. Actual displacements produce swing and offset errors but these are negligible.

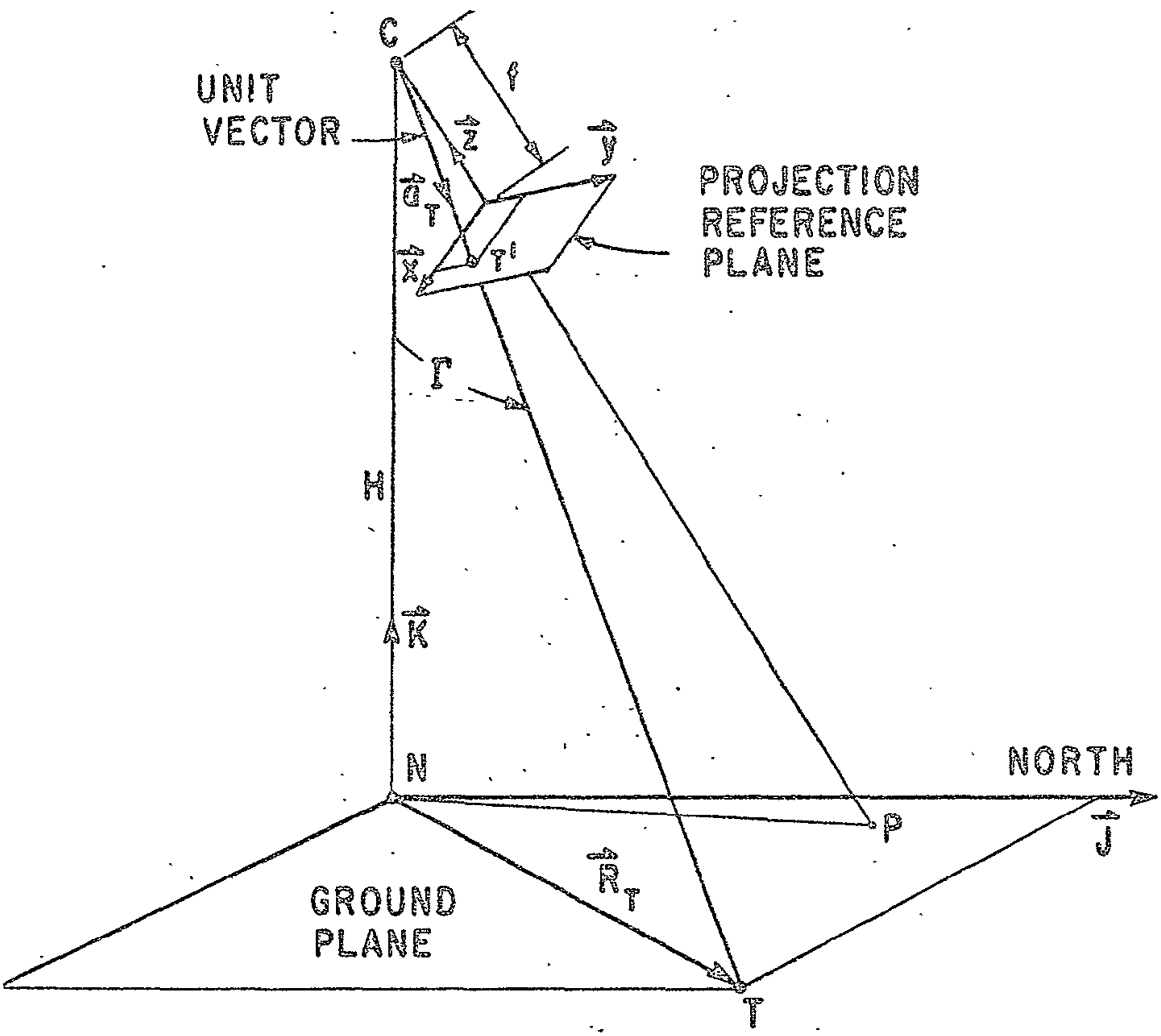
Consider the situation shown in Figure A-4. The aircraft has undergone an attitude shift so that the projection reference plane (parallel to the film image plane but reflected through the optical node, C, through a distance equal to the focal length, f) is at some arbitrary angle.

In the general case, the camera system could be tipped at some oblique angle, so the first transform should describe the tilt. Then

$$\begin{bmatrix} i \\ j \\ k \end{bmatrix}_1 \equiv Q_1 = R_{10} \begin{bmatrix} i_o \\ j_o \\ 0 \end{bmatrix} \equiv R_{10} Q_o . \qquad \text{(A-2)}$$

For a forward oblique, R_{10} represents a negative rotation about $\vec{j}_o$ of δ_F^o, so

$$R_{10} = \begin{bmatrix} \cos\delta_F & 0 & \sin\delta_F \\ 0 & 1 & 0 \\ -\sin\delta_F & 0 & \cos\delta_F \end{bmatrix} . \qquad \text{(A-3a)}$$



FRAME PHOTOGRAPHY

FIGURE A-4.

For a <u>side oblique</u>, R_{10} represents, say, a positive rotation about $\vec{i}_o$ of δ_s^o, so

$$R_{10} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\delta_s & -\sin\delta_s \\ 0 & \sin\delta_s & \cos\delta_s \end{bmatrix} \qquad \text{(A-3b)}$$

Similarly, for roll then pitch then heading:

$$Q_2 = R_{21}\, Q_1$$

$$Q_3 = R_{32}\, Q_2$$

$$Q_4 = R_{43}\, Q_{32} = R_{43}\, R_{32}\, R_{21} R_{10} Q_0 \equiv RQ_o. \qquad \text{(A-4)}$$

where

$$R_{21} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix} \quad \underline{\text{Roll}} \qquad \text{(A-5)}$$

$$R_{32} = \begin{bmatrix} \cos\rho & 0 & \sin\rho \\ 0 & 1 & 0 \\ -\sin\rho & 0 & \cos\rho \end{bmatrix} \quad \underline{\text{Pitch}} \qquad \text{(A-6)}$$

$$R_{43} = \begin{bmatrix} \sin\theta & -\cos\theta & 0 \\ \cos\theta & \sin\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \underline{\text{Heading}} \qquad \text{(A-7)}$$

:he vector $\overrightarrow{CT}'$ in Figure A-4 is equal to

$$Q^*_\circ = \begin{bmatrix} x_T \\ y_T \\ -f \end{bmatrix} \tag{A-8}$$

n the rotated $(\vec{x}, \vec{y}, \vec{z})$ system. Therefore, the components of $\overrightarrow{CT}'$ n the $(\vec{I}, \vec{J}, \vec{K})$ system are given by

$$Q^*_4 = R \cdot Q^*_\circ \tag{A-9}$$

Define the unit vector $\vec{a}_T$ as shown. Then its components <u>in the ground system</u> are:

$$\vec{a}_T = \frac{RQ^*_\circ}{|RQ_\circ^*|} \tag{A-10}$$

From the figure,

$$\overrightarrow{NT} = H\vec{K} + |\overrightarrow{CT}| \; \vec{a}_T \tag{A-11}$$

Further,

$$|\overrightarrow{CT}| = \frac{H}{\cos \Gamma} = \frac{H}{-\vec{a}_T \cdot \vec{K}} \tag{A-12}$$

Therefore,

$$\overrightarrow{NT} = H\vec{K} - \frac{H\,\vec{a}_T}{\vec{a}_T \cdot \vec{K}} \tag{A-13}$$

But

$$\vec{a}_T = a_1 \vec{I} + a_2 \vec{J} + a_3 \vec{K} \tag{A-14}$$

where

$$a_3 = \vec{a}_T \cdot \vec{K} \tag{A-15}$$

Then

$$\vec{NT} = H\left[\vec{K} - \frac{1}{\vec{a}_T \cdot \vec{K}}\left\{a_1 \vec{I} + a_2 \vec{J} + (a_T \cdot \vec{K})\vec{K}\right\}\right]$$

$$= \frac{-H}{a_3}\left(a_1 \vec{I} + a_2 \vec{J}\right) \tag{A-16}$$

Therefore, the local ground coordinates of T are:

$$\begin{bmatrix} I_T \\ J_T \\ 0 \end{bmatrix} \equiv \vec{R}_T = \frac{-H}{a_3}\begin{bmatrix} a_1 \\ a_2 \\ 0 \end{bmatrix} \tag{A-17}$$

A.2.2 Profile Sensors

Non-scanning profile sensing devices correspond, mathematically, to a special case of the above where

$$Q_{\circ}^{*} = \begin{bmatrix} 0 \\ 0 \\ -f \end{bmatrix}$$

That is, the treatment is the same as would be used to locate the ground intersection, P, of the principal point in a camera image. Then the values of interest are:

$$R_p = \frac{-H}{a_3} \begin{bmatrix} a_1 \\ a_2 \\ 0 \end{bmatrix} \qquad \text{(A-18)}$$

Some profile equipments can be adjusted in look angle. This corresponds to an oblique camera offset and merely implies that the R_{10} transform must be included in the calculations.

A. 2. 3 Panoramic Photography

From Figure A-5, the photographic coordinates of point T′ are (L, fγ). Further, the instantaneous vector $\vec{CT}'$ is

$$\vec{CT}' \equiv Q^*_o = \begin{bmatrix} L \\ f \sin\gamma \\ -f \cos\gamma \end{bmatrix} \tag{A-19}$$

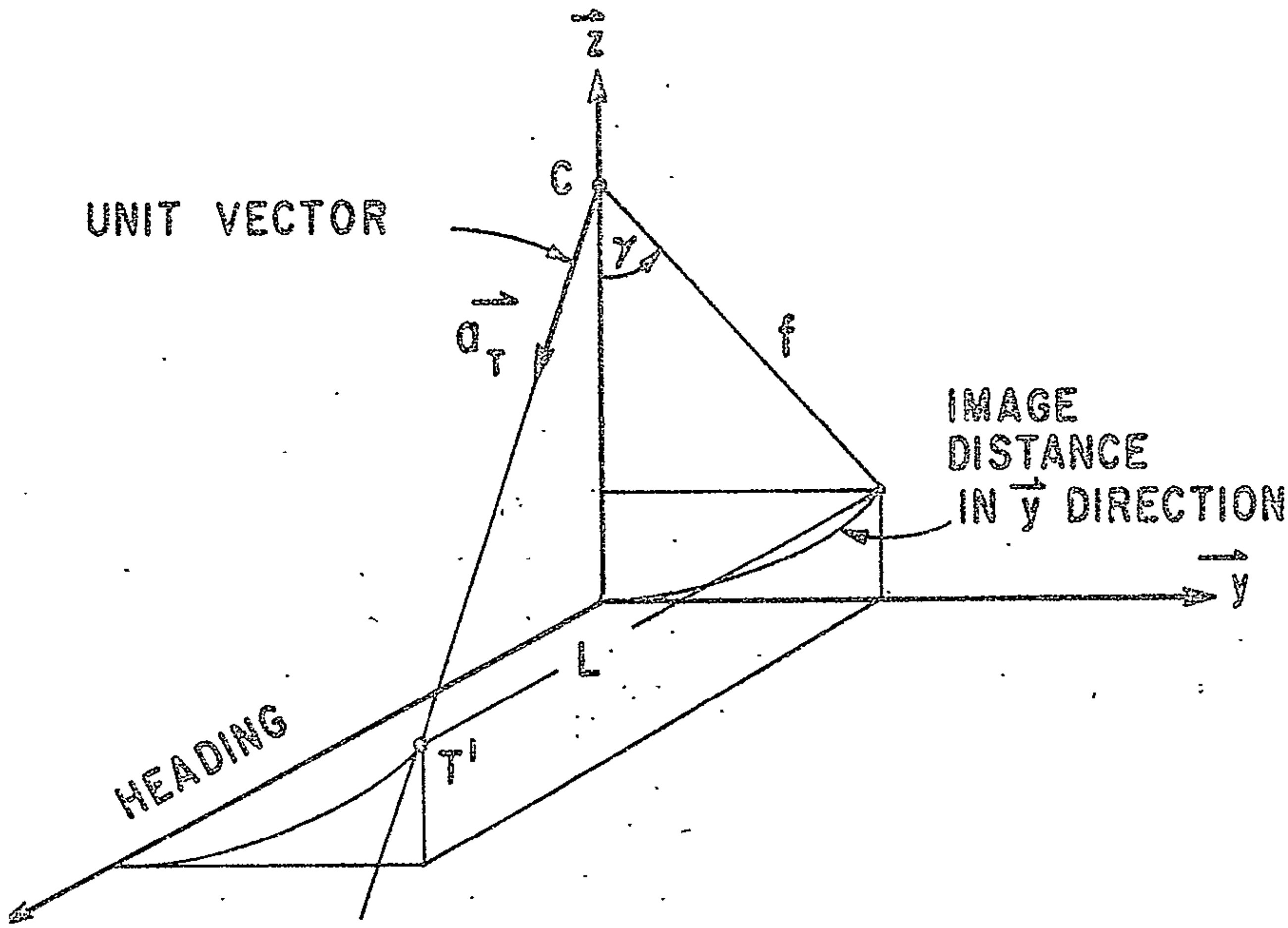
in the ($\vec{x}$, $\vec{y}$, $\vec{z}$) system.

Then, in the ground system, the characteristic unit vector is again

$$\vec{a}_T = \frac{RQ^*_o}{|R\ Q^*_o|} \tag{A-20}$$

A. 2. 3. 1 Vehicle Motion

Unlike frame photography, where an area is exposed simultaneously, panoramic photography employs a mechanical scan of a longitudinally oriented slit. Rotation is about a line parallel to the longitudinal axis of the aircraft. Active scan time varies from equipment to equipment but is generally on the order of seconds. This leads to the familiar "S - distortion" due to vehicle travel within the frame, and raises the possibility of additional distortions from altitude and attitude shifts that could occur during the same interval. Relative geometry ($\vec{x}$, $\vec{y}$, $\vec{z}$ system) is unaffected but projections to the local ground



PANORAMIC PHOTOGRAPHY

FIGURE A-5.

system must be modified, i.e.,

$$R = R\ (t).$$

This can be implemented by using that portion of the NAV data corresponding to the frame interval and interpolating between samples where necessary. The transform equation could then be treated as a function of time-variant NAV parameters. However, for any one frame, all image points should be referenced to one local ground coordinate system. A convenient choice is one whose origin is the nadir point at the beginning of the camera sweep.

See also the discussion in Section 8.3.2.

A.2.4 Side Looking Airborne Radar (SLAR)

Since the SLAR is an active ranging system with wide angular coverage in the cross-track direction it is, in effect, automatically compensated for roll. Furthermore, since the on-board recorder lays down a line image (per radar transmission) which is some function of time, the collection geometry differs from the camera cases. Figure A-6 illustrates a generalized situation, with the $\vec{x}$, $\vec{y}$, $\vec{z}$ origin at the nadir point.

Assume that the on-board system records the continuous return over slant ranges S_{min} to S_{max}.

Then ground distances to an arbitrary point T are:

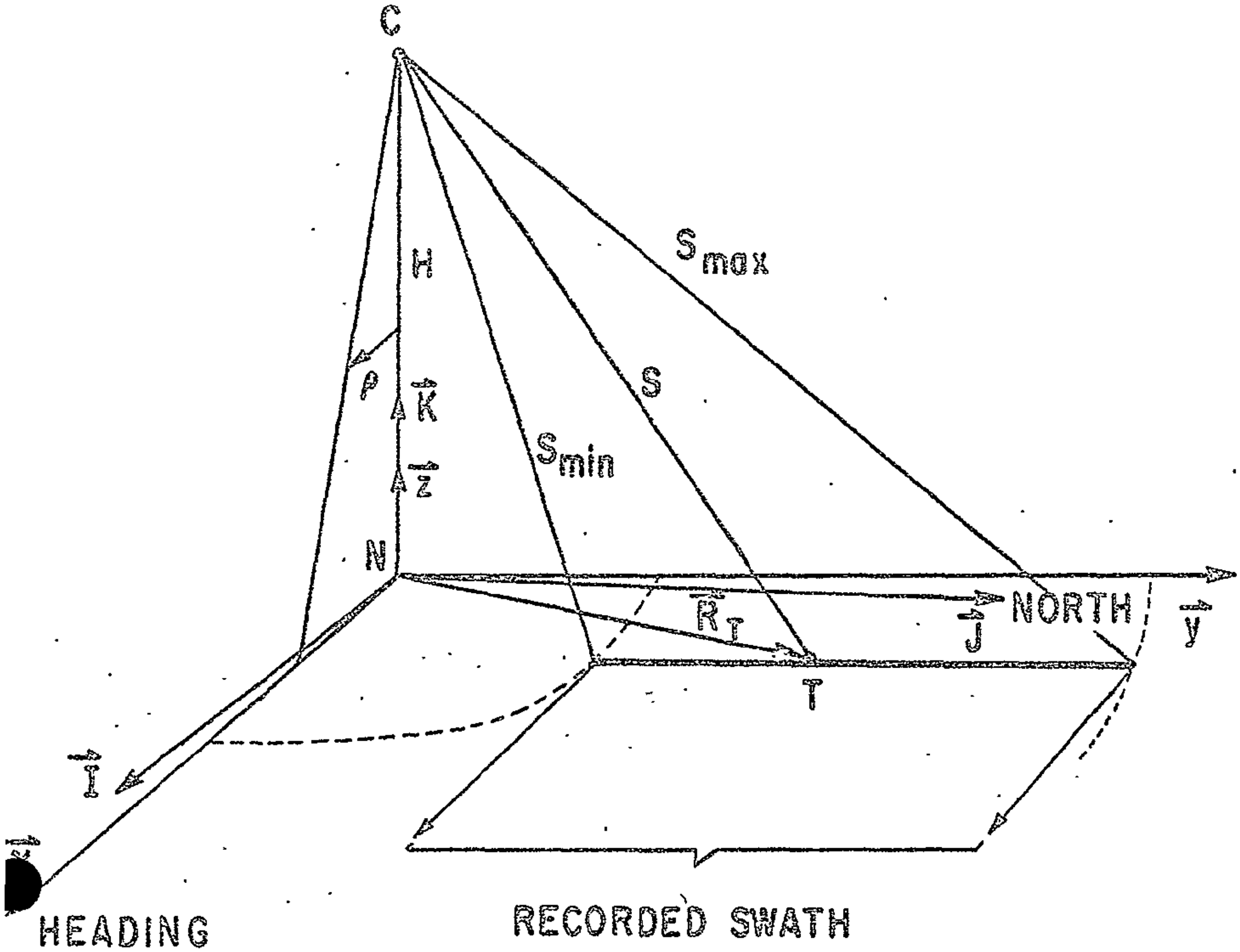
$$x_T = H \tan \rho \qquad \text{(A-21)}$$

$$y_T = \left(S^2 - H^2 \cdot \sec^2 \rho \right)^{1/2}$$

Hence, in the desired ($\vec{I}$, $\vec{J}$, $\vec{K}$) reference system

$$\vec{R}_T = R_{43} \begin{bmatrix} x_T \\ y_T \\ 0 \end{bmatrix} \qquad \text{(A-22)}$$

where R_{43} is the heading rotation matrix defined in equation (A-7).



SLAR RANGING

FIGURE A-6

The conversion from image coordinates to local ground coordinates is governed by the characteristics of the film recorder.

If the recorder CRT uses a linear time base, then the image distance to point T' in the y direction is

$$y'_T = (S - S_{min})\, k_{ys} \qquad \text{(A-23)}$$

where k_{ys} is the scale factor in the y direction, relative to slant range.

Some systems use a non-linear CRT sweep in order to rectilinearize the line image. However, pitch compensation is generally omitted, so that

$$y'_T = \left[(S^2 - H^2)^{1/2} - (S^2_{min} - H^2)^{1/2} \right] k_{yg} \qquad \text{(A-24)}$$

where k_{yg} is the scale factor in the y direction, relative to ground range.

Therefore, to relate image distance y'_T to ground distance y_T, solve either equation (A-23) or (A-24) for S and substitute the value in (A-21).

The x dimension on a SLAR image film is essentially a time line. Position and attitude data corresponding to any scan line are known via time comparison with the NAV readings.

The nominal distance from some reference $x_\circ$ (at $t_\circ$) to the scan line of interest is:

$$x'_{nom.} = x_\circ \int_{t_\circ}^{t_T} V_{film} \, dt \qquad \text{(A-25)}$$

If pitch correction is included in the x dimension, the actual image position will be

$$x'_T = x'_{nom.} + k_x \int_{t_\circ}^{t_T} H(t) \tan \rho(t) \, dt \qquad \text{(A-26)}$$

where k_x is a scale factor in the x direction. Ideally, $k_x = k_y$ but in practice this may or may not be true.

From the foregoing, it is clear that all non-linear compensations at the recorder in the x direction complicate the process of relating image points to the associated scan times.

A. 2. 5 Point Scanners

Figure A-7 shows the characteristic geometry for line and arc type point scanners. As with the SLAR, correction calculations depend on the nature of the data recording equipment. Two classes will be considered:

- Magnetic tape recorder
- CRT film recorder

A. 2. 5. 1 Line Scanner

The unit vector $\overrightarrow{a_T}$ can be found by defining

$$CT' \equiv Q^*_0 = \begin{bmatrix} 0 \\ f \tan \alpha \\ -f \end{bmatrix} \qquad \text{(A-27)}$$

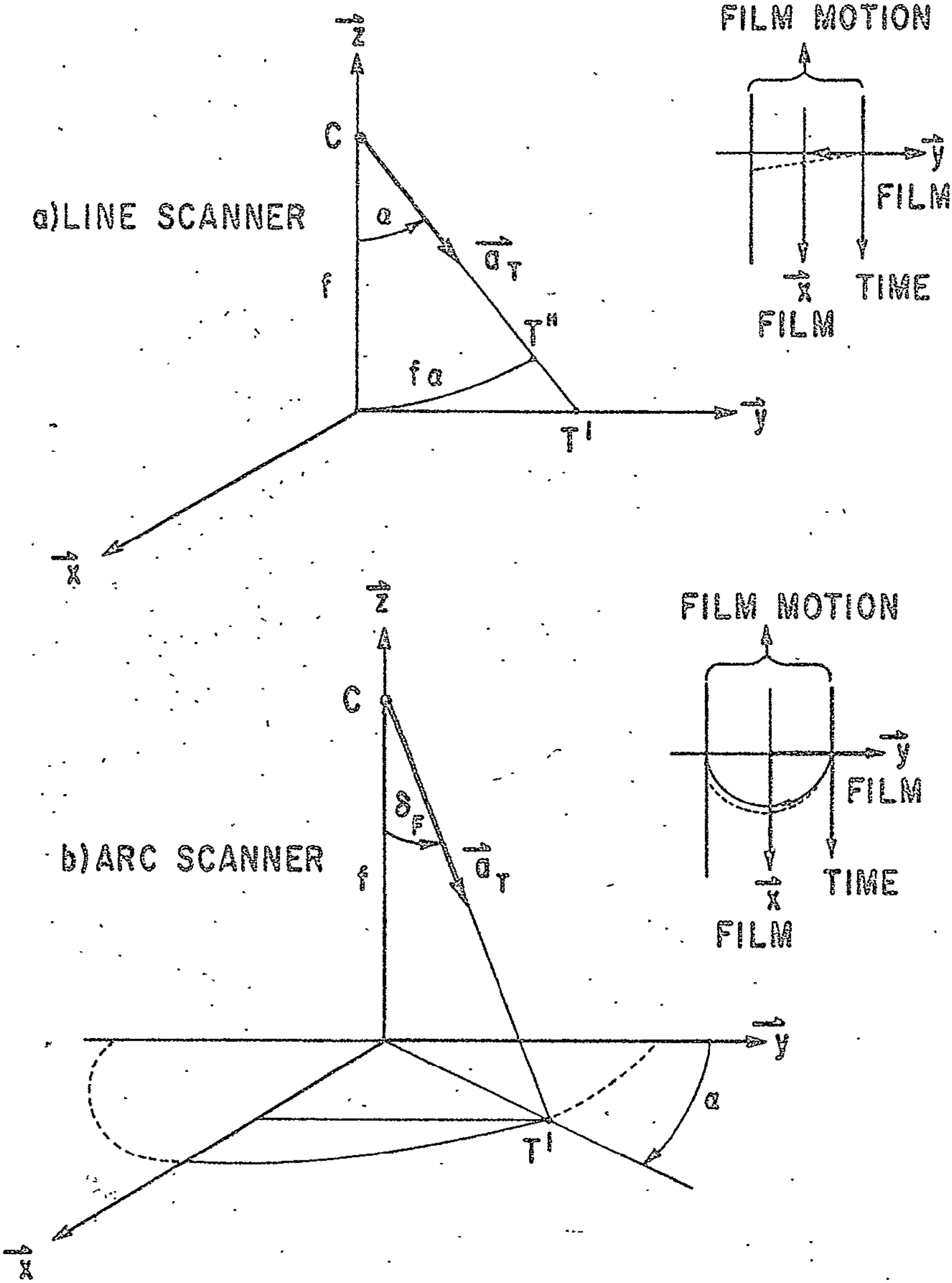
If data is recorded on magnetic tape, the distance from line sync to the element of interest is merely $K_1 \alpha$, where K_1 is a recorder constant.

Vehicle motions during active scan can be compensated by using $R = R(t)$, if necessary, then translating the ground coordinates as a function of time and track velocity. From Figure A-2,

$$\Lambda = 90 - (\theta + \eta) \qquad \text{(A-28)}$$

and the track vector, $\vec{V}$, may be defined as:

$$\vec{V} = V \cos \Lambda \; \vec{I} + V \sin \Lambda \; \vec{J} \qquad \text{(A-29)}$$



POINT SCANNERS

FIGURE A-7.

then

$$\vec{V} = V \sin(\theta + \eta)\,\vec{I} + V \cos(\theta + \eta)\,\vec{J} \quad \text{(A-30)}$$

Finally, the translation becomes:

$$I_T = I_{T_\circ} + (t - t_\circ)\, V \sin(\theta + \eta) \quad \text{(A-31)}$$

$$J_T = J_{T_\circ} + (t - t_\circ)\, Y \cos(\theta + \eta)$$

Film recording systems introduce further complexities because, in general, they:

a) only partially (if at all) compensate for vehicle motions in the sweep of the CRT electron beam;

b) introduce new motion distortions because the recording film moves in only one dimension whereas ground velocity varies in two:

c) exhibit deflection distortions and alignment errors (X and Y position and scale); and

d) imperfectly generate the correction functions they use.

Therefore, scanner film strips do not lend themselves to coordinate calculations of accuracies comparable to those for photographic images. Typically, the following assumptions are valid and permit an approximate calculation to be made:

- All recorder errors are negligible;
- Roll compensation is included in the y sweep, but not pitch, yaw or altitude effects:
- The y sweep may or may not be rectilinearized;
- There is no x component of the CRT sweep, and film travel during the sweep produces a negligible skew of the line image.

Consider the x dimension on the film to be a time line. The center of the strip corresponds to nadir imagery along the ground track. Then, relative to the center line,

$$y_{T''} = Kf\ \alpha^* \qquad \text{(A-32)}$$

or, if the sweep has been rectilinearized,

$$y_{T'} = K\ f\ \tan \alpha^* \qquad \text{(A-33)}$$

where

$$\begin{aligned} K &= \text{recorder constant} \\ \alpha^* &= \text{net angle} = \alpha + \omega \qquad \text{(A-34)} \\ \alpha &= \text{scan angle} \\ \omega &= \text{roll angle} \end{aligned}$$

If the sweep is <u>linear,</u> equation (A-32) converts image distance in the y direction to net angle, α^*. Then scan angle can be calculated and ground coordinates found as in the case of tape recorded data.

For rectilinearized images, an absence of aircraft pitch would make the corresponding ground distance

$$x_T = 0$$

$$y_T = \frac{y_T'}{K_s} = H \tan \alpha^* \qquad \text{(A-35)}$$

where

$$K_s = \text{scale factor} = K\, f/H$$

However, a constant pitch condition of $\rho°$ leads to

$$x_T = H \tan \rho$$

$$y_T = \frac{y_T'}{K_s} \sec \rho \qquad \text{(A-36)}$$

Then, as for SLAR imagery, the $(\vec{I}, \vec{J}, \vec{K})$ coordinates become:

$$\vec{R}_T = R_{43} \begin{bmatrix} x_T \\ y_T \\ 0 \end{bmatrix} \qquad \text{(A-37)}$$

Finally, the translation corrections indicated by equations (A-31) could be included. However, at scan intervals on the order of 10^{-1} to 10^{-2} seconds, or less, aircraft travel is likely to introduce smaller distortions than those from the film recorder which were ignored in the earlier calculations.

A. 2. 5. 2 Arc Scanner

Arc Scanner data will normally be recorded linearly in time on magnetic tape but it is conceivable that a CRT recorder could be used. If so, it would, presumably, scan out a circular arc and would not be compensated for aircraft attitude. For either type of recording,

$$\overrightarrow{CT}' \equiv Q^*_o = \begin{bmatrix} f \tan \delta_F \sin \alpha \\ f \tan \delta_F \cos \alpha \\ -f \end{bmatrix} \quad \text{(A-38)}$$

The data distance on tape is $K_1 \alpha$, where K_1 is a recorder constant.

For the film recorder, assume that:

- the $\vec{x}$, $\vec{y}$ origin is as shown on Figure A-7 (b)
- film motion produces negligible sweep displacement during any one scan (this could easily be compensated for by adding a small -x component to the sweep velocity vector)

Then the image coordinates of interest can be written as:

$$x_{T'} = \frac{f \tan \delta_F}{K_1} \sin \alpha$$

$$y_{T1} = \frac{f \tan \delta_F}{K_1} \cos \alpha \quad \text{(A-39)}$$

where K_1 is a recorder constant. Finally, the reference vector becomes:

$$\overrightarrow{CT}' \equiv Q^*_o = \begin{bmatrix} K_1 \; x_{T'} \\ K_1 \; y_{T'} \\ -f \end{bmatrix} \qquad (A-40)$$

A. 2. 6 Push-Broom Imagers

Since no sensor of this class is currently flying, and since the actual array configuration can vary widely, the only case treated here will be the ideal one.

Assume:

- A perfectly linear array over a cross-track line field of view;
- Magnetic tape recording only;
- Perfect formatting; i. e., all data elements per scan line are ordered in a linear sequence on the tape to be corrected.

The Line Scanner sketch, Figure A-7(a), is useful here. There is no scan angle, α, but the dimension of interest is the data distance equivalent to $y_{T'}$. If the scan time to detector element T' is $t_{T'}$, the desired data distance is $Kt_{T'}$, so

$$\overrightarrow{CT}' \equiv Q^*_o = \begin{bmatrix} 0 \\ Kt_{T'} \\ -f \end{bmatrix} \qquad (A-41)$$

A. 2. 7 TV Sensors

Television - type sensors such as the RBV, with shuttered exposures, form images that have internal geometric distortions due to deflection non-linearities. Once these are removed, via a corrective mapping transform, the resultant image can be coordinate-converted in exactly the same manner as a frame photograph.

A.3 TRANSFORMATION FROM LOCAL GROUND TO GEOCENTRIC COORDINATES

Thus far, sensor collections have been related to local ground coordinates ($\vec{I}, \vec{J}, \vec{K}$). The next step is to convert the local values into a global coordinate system. It is desirable to eventually express them in the geographical system of latitude/longitude because:

1) This is a familiar system whose relationships to other world-wide systems have been developed;

2) The transform from local coordinates is straightforward;

3) Airborne navigational systems generate latitude and longitude values for data recording.

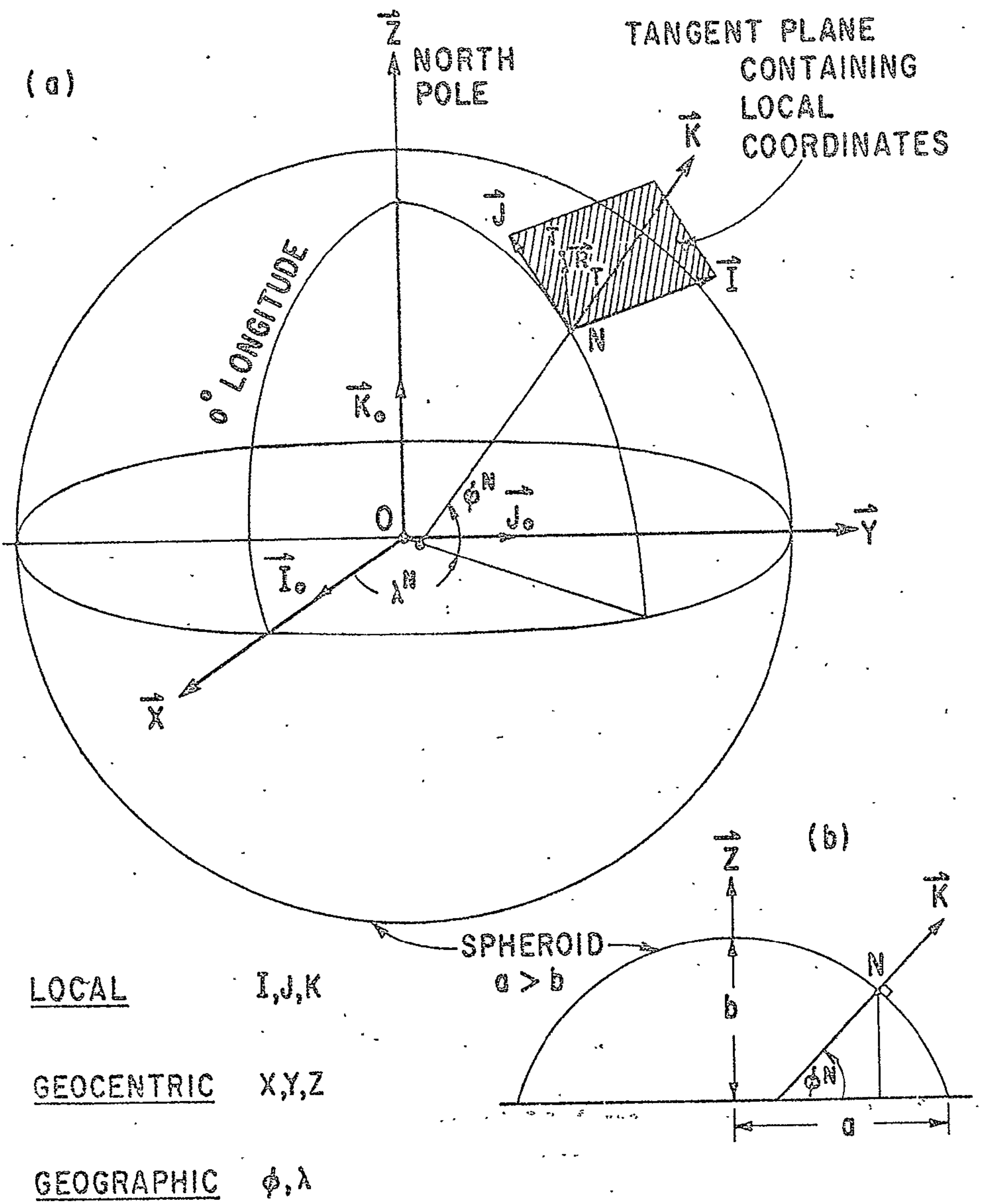
Figure A-8 illustrates the transform geometry. Vectors $\vec{I}_o$, $\vec{J}_o$, $\vec{K}_o$ represent the initial conditions on the local system $\vec{I}$, $\vec{J}$, $\vec{K}$. They are aligned with a geocentric rectangular system $\vec{X}$, $\vec{Y}$, $\vec{Z}$ as shown. Hence, the path to geographic coordinates is via a preliminary rotation and translation into the geocentric system.

A complication arises in that the Earth is not a perfect sphere. Assume a standard spheroid where, as shown in part (b) of the diagram,

a = semi major axes

b = semi minor axis

The local ground plane is tangent to the spheroid at point N.



FINAL COORDINATE TRANSFORMS

FIGURE A-8.

Direction numbers of the normal to the surface at some point (X, Y, Z) are:

$$\frac{2X}{a^2}, \quad \frac{2Y}{a^2}, \quad \frac{2Z}{b^2}$$

$$\text{or} \qquad b^2 X, \quad b^2 Y, \quad a^2 Z$$

Direction numbers of the vector projection of the normal on to the X, Y plane are Xb^2, Yb^2, O.

Therefore

$$\cos \emptyset = \sqrt{\frac{b^4 X^2 + b^4 Y^2}{b^4 X^2 + b^4 Y^2 + a^4 Z^2}} \tag{A-45}$$

From equation (A-44)

$$X^2 + Y^2 = \frac{a^2}{b^2}(b^2 - Z^2) \tag{A-46}$$

Equation (A-45) then reduces to:

$$\cos \emptyset = \frac{ab\sqrt{b^2 - Z^2}}{\sqrt{a^2 b^2 (b^2 - Z^2) + a^4 Z^2}} \tag{A-47}$$

from which

$$Z^2 = \frac{b^4 \sin^2 \emptyset}{a^2 \cos^2 \emptyset + b^2 \sin^2 \emptyset} \tag{A-48}$$

The eccentricity of an ellipsoid is defined as

$$e = \sqrt{1 - \frac{b^2}{a^2}} \tag{A-49}$$

so

$$b^2 = a^2 (1-e^2) \tag{A-50}$$

Equation (A-48) may now be rewritten as

$$Z = \frac{a}{\sqrt{1-e^2 \sin^2 \phi}} (1-e^2) \sin \phi \tag{A-51}$$

Define

$$M = \frac{a}{\sqrt{1 - e^2 \sin^2 \phi}} \tag{A-52}$$

Therefore

$$\underline{\underline{Z = M (1-e^2) \sin \phi}} \tag{A-53}$$

Equations (A-46) and (A-50) may be combined to form:

$$X^2 + Y^2 = \frac{1}{1-e^2} \left[a^2 (1-e^2) - Z^2 \right] \tag{A-54}$$

But, from (A-53), this becomes:

$$\begin{aligned} X^2 + Y^2 &= \frac{1}{1-e^2} \left[a^2 (1-e^2) - M^2 (1-e^2) \sin^2 \phi \right] \\ &= a^2 - M^2 (1-e^2) \sin^2 \phi \\ &= a^2 - \frac{a^2}{1-e^2 \sin^2 \phi} (1-e^2) \sin^2 \phi \\ &= M^2 \cos^2 \phi \end{aligned} \tag{A-55}$$

From Figure A-8

$$\cos \lambda = \frac{X}{\sqrt{X^2 + Y^2}} \qquad \text{(A-56)}$$

Therefore

$$\underline{\underline{X = M \cos \emptyset \cos \lambda}} \qquad \text{(A-57)}$$

From (A-55),

$$y^2 = M^2 \cos^2 \emptyset - X^2 \qquad \text{(A-58)}$$

which reduces to

$$\underline{\underline{Y = M \cos \emptyset \sin \lambda}} \qquad \text{(A-59)}$$

Equations (A-53), (A-57) and A-59) describe the conversion of any point in the geographic coordinate system to the geocentric rectangular coordinate system. Therefore, given the nadir point geographic coordinates ($\emptyset^N$, λ^N), the translation matrix required is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_N = M \begin{bmatrix} \cos \emptyset^N \cos \lambda^N \\ \cos \emptyset^N \sin \lambda^N \\ (1-e^2) \sin \emptyset^N \end{bmatrix} \qquad \text{(A-60)}$$

A.4 TRANSFORMATION FROM GEOCENTRIC TO GEOGRAPHIC COORDINATES

From equation (A-60) it follows immediately that

$$\lambda = \tan^{-1} \frac{Y}{X} \qquad \text{(A-61)}$$

$$\emptyset = \tan^{-1} \frac{Z}{(1-e^2)\sqrt{X^2 + Y^2}} \qquad \text{(A-62)}$$

A.5 RELATED TRANSFORMS

There are three further transforms that should be considered in implementing the coordinate adjustment software:

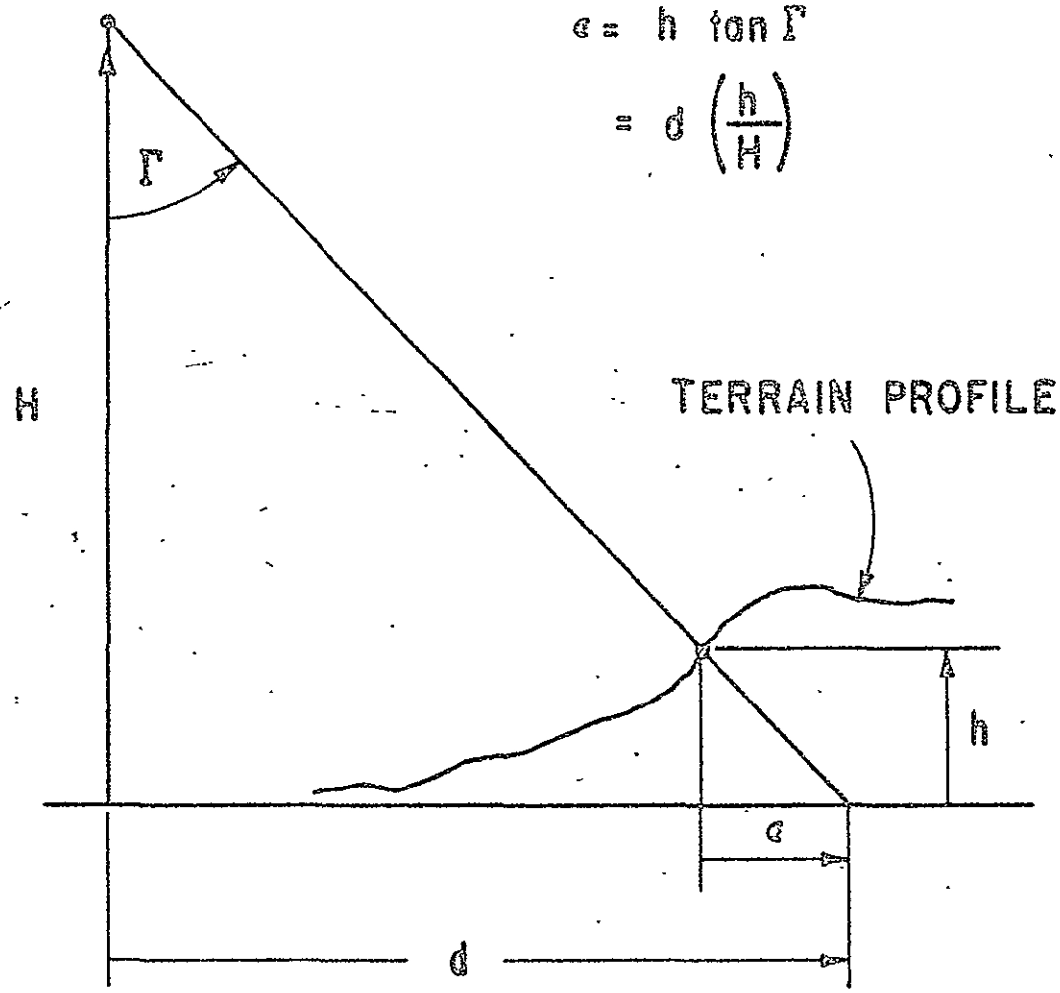
- Correction for Earth's Curvature and Atmospheric Refraction
- Correction for Terrain Relief
- Map Projection Transforms

None of them are given here.

The first depends on which atmospheric model is chosen, and several are documented in the literature; furthermore, at low altitudes or for small angles from the vertical it is a very good approximation to treat the Earth as a flat plane and neglect refraction.

Displacements due to Terrain Relief have a very simple geometry (Figure A-9) and correction implies the existence of a suitably detailed, three dimensional digital map base. There has been no indication to date that this is even being contemplated.

Map transforms from Latitude/Longitude to the UTM System, Lambert Conformal Conic, etc. are well known and well documented.



DISPLACEMENT DUE TO TERRAIN RELIEF

FIGURE A-9.

GLOSSARY OF SYMBOLS

ω	Roll angle
ρ	Pitch angle
η	Drift angle
θ	Heading angle
$\vec{i}_o, \vec{j}_o, \vec{k}_o$	"Zero" condition reference
x, y, z	Sensor data coordinates (origin at C)
I, J, K	Local ground coordinates (origin at N)
X, Y, Z	Geometric coordinates (origin at 0)
ϕ, λ	Geographic coordinates (Latitude, Longitude), based on the Earth as an ellipsoid
C	Sensor equivalent nodal point
N	Nadir Point
O	Center of the Earth
f	Sensor equivalent focal length
H	Aircraft altitude above ground datum plane
δ_F	Forward oblique tilt angle of sensor
δ_S	Side oblique tilt angle of sensor
T^1	Arbitrary point in sensor data reference plane
T	Corresponding point in ground datum plane
$\vec{a}_T$	Unit vector in the direction $\overrightarrow{CT}'$
Γ	Angle between $\vec{a}_T$ and the local vertical
a_1, a_2, a_3	Components of $\vec{a}_T$, in the I, J, K system
S	Slant range $\overrightarrow{CT}$
k_{ys}	CRT Recorder Scale factor in the y direction, relative to slant range
k_{yg}	CRT Recorder scale factor in the y direction, relative to ground range
K_1	Recorder constant
Λ	Angle between the track direction and East
$\vec{V}$	Aircraft velocity vector
V	Magnitude of V
α	Sensor scan angle about the longitudinal axis of the vehicle

GLOSSARY (Continued)

α^*	Net angle, $\alpha + \omega$
K_s	Scale factor, Mf/H
$t_{T'}$	Scan time to element T' in a push-broom sensor
a	Semi-major axes of the standard spheroid
b	Semi-minor axis of the standard spheroid
e	Eccentricity of the ellipsoid
M	Mathematical variable (see Equation A-52)

APPENDIX B

FUNCTIONAL TRANSFORMS

FOREWORD

Appendix B describes some further calculations which are necessary in the operational system for various manipulative purposes.

APPENDIX B CONTENTS

DESCRIPTION		PAGE

ILLUSTRATIONS		

B.1 FRAME COVERAGE

This section of Appendix B presents the sequence of steps necessary to determine which ground area bins are partially or totally included on an arbitrary frame image. The development follows the explanation given in Section 9.2 of the main body of the report. Figure 9-4 is repeated here as a convenient reference.

If measured relationships are unavailable, calculate the ground coordinates of the four frame corners. Assume a flat horizontal ground plane and use the coordinate transform equations developed in Appendix A.

2. Determine which bins contain the four ground points. For a point (ϕ_i, λ_i), the associated bin is $M_i N_i$ where:

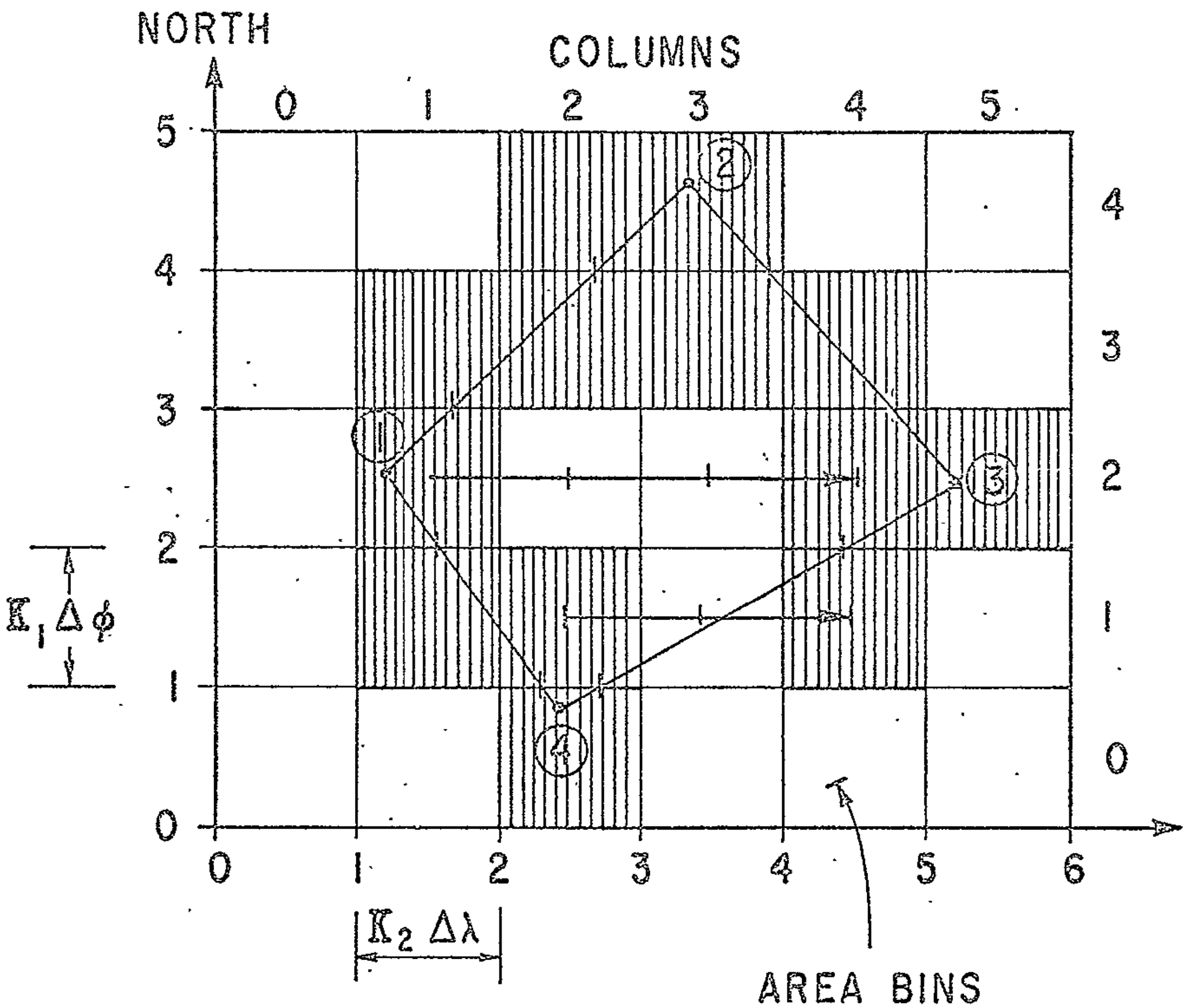
$$M_i = \frac{\phi_i}{K_1 \Delta \phi} - r_i = \text{row number} \tag{B-1}$$

$$N_i = \frac{\lambda_i}{K_2 \Delta \lambda} - r^*_i = \text{column number} \tag{B-2}$$

r_i, r^*_i = residue fractions

$i = 1, 2, 3, 4$

3. Determine the relative N-S, E-W locations of the four bins by finding maximum and minimum row and column numbers. Use this information to control the direction signs in subsequent calculations.



COVERAGE OF A PHOTOGRAPHIC FRAME

FIGURE 9-4.

4. Calculate the intersection of each frame edge with all row boundaries between the two end points. If consecutive points 1-4 are related as shown:

Vector $1 \rightarrow 2$

a) Form $M_1 + 1$, $M_1 + 2$, $\ldots M_2 = M_i$

b) In this region:

$$\lambda_i = \lambda_1 + (\lambda_2 - \lambda_1) \frac{(\phi_i - \phi_1)}{\phi_2 - \phi_1} \qquad \text{(B-3)}$$

c) Substitute $\phi_i = M_i$ and solve for

$$\lambda_i = \lambda_{11}, \lambda_{12}, \ldots\ldots \lambda_2 . \qquad \text{(B-4)}$$

d) Calculate corresponding values of N_i by substituting values from (B-4) into (B-2)

e) Store bin numbers M_i N_i and M_{i-1}, N_i for all i.

Similarly, for any vector $e \rightarrow f$:

$$\lambda_i = \lambda_e + (\lambda_f - \lambda_e) \frac{(\phi_i - \phi_e)}{\phi_f - \phi_e} \qquad \text{(B-5)}$$

5. Repeat the calculations and bin number storage for the four frame edge vectors.

6. Sort the stored bin numbers by row and then by column, starting with the highest row. Eliminate redundant entries. For the case shown in Figure 9-4 this would lead to five lists:

1) 42, 43

2) 31, 32, 33, 34

3) 21, 24, 25

4) 11, 12, 14

5) 02

7 Examine each list and fill in the included bins by combining the given row number with all missing column numbers in the listed range. In the example, the new entires thus formed would be 22, 23, 13.

At this point, the computation is complete.

B.2 SENSOR FOOTAGE

If a system interrogation is posed in terms of a particular set of ground coordinates; data retrieval can be accelerated by calculating the film (or tape) footage to the region of interest before testing for "frame" coverage overlap. The calculation assumes that the vehicle has constant ground velocity for a known mission leg that flies within collection range of the target. Since the value derived is only approximate, any implementing program should allow for some search in both directions about the nominal frame.

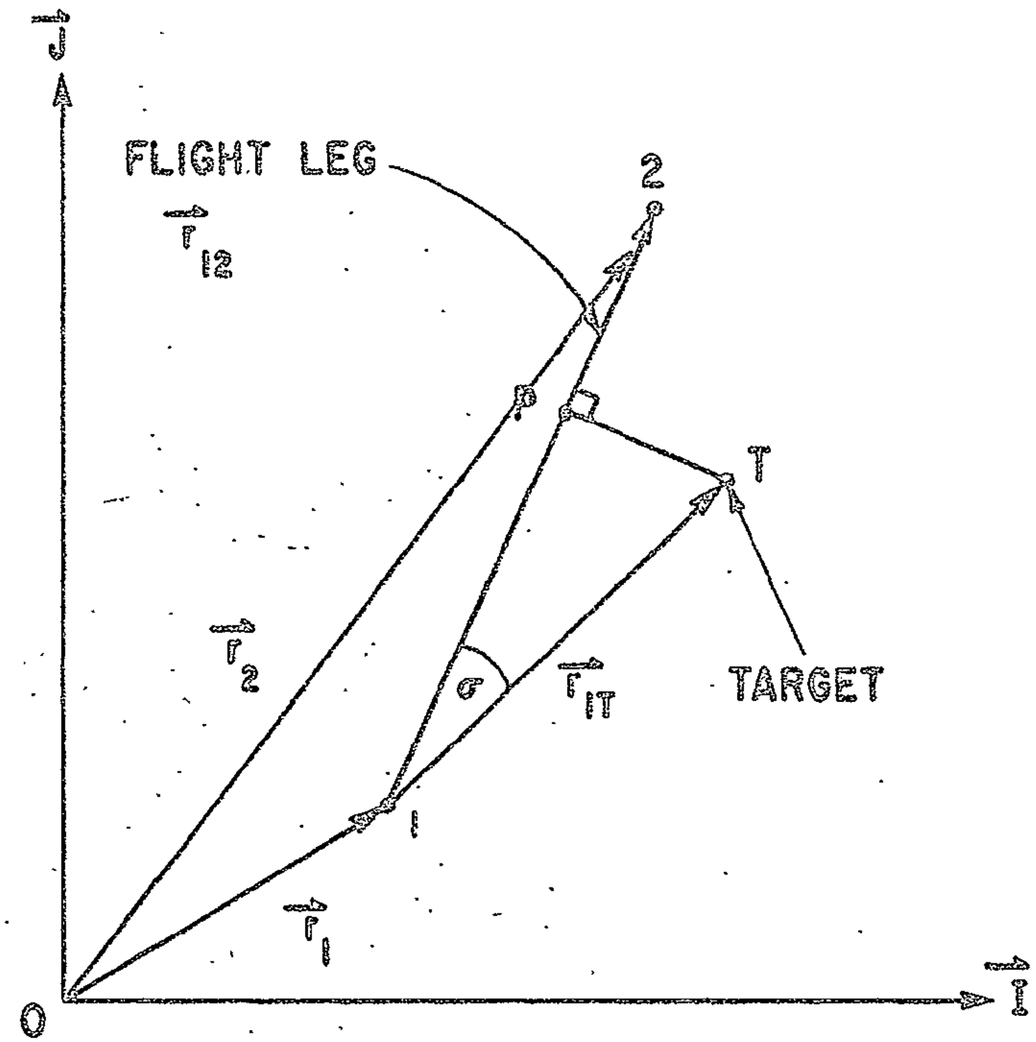
The assumed knowns are:

- ground speed
- ground coordinates of both end points of the leg, and of the target
- time at both end points of the leg
- footage to the beginning of the leg
- camera cycling rate (or recorder tape speed)

It is also assumed that the sensor is operating during the specified flight leg, but the operational software should check.

Referring to Figure B-1, the footage number desired is simply

$$F_T = F_1 + F_{12} \frac{r_{1p}}{r_{12}} \qquad \text{(B-6)}$$



FILM/TAPE FOOTAGE COMPUTATION GEOMETRY

FIGURE B-1.

where

F_T = Footage to the target

F_1 = Footage to point 1 (given)

F_{12} = Amount of film exposed (or tape used)

r_{1p} = Distance along the flight line from point 1 to the perpendicular intercept from the target

r_{12} = Ground distance of the mission leg.

All inputs in latitude/longitude are first converted to the rectangular coordinate system as per Appendix A.

Then:

$$r_{12} = \sqrt{(I_2 - I_1)^2 + (J_2 - J_1)^2} \tag{B-7}$$

$$F_{12} = (t_2 - t_1) \times \text{cycling rate or tape speed} \tag{B-8}$$

$$\begin{aligned} r_{1p} &= \left| \vec{r}_{1T} \right| \cos \sigma \\ &= \frac{\vec{r}_{1T} \cdot \vec{r}_{12}}{\left| \vec{r}_{12} \right|} \\ &= \frac{(\vec{r}_T - \vec{r}_1) \cdot (\vec{r}_2 - \vec{r}_1)}{\left| \vec{r}_2 - \vec{r}_1 \right|} \end{aligned} \tag{B-9}$$

In component form this becomes:

$$r_{1p} = \frac{(I_T - I_1)(I_2 - I_1) + (J_T - J_1)(J_2 - J_1)}{\sqrt{(I_2 - I_1)^2 + (J_2 - J_1)^2}} \tag{B-10}$$

APPENDIX C

EQUIPMENT SURVEY CHARTS

FOREWORD

This Appendix contains an in-depth equipment survey of the important subsystems that comprise the Automatic Data Correlation System. All the major non-computer functions involved in Preprocessing, Parameter Processing, and Correlation Processing are included in this survey.

Each subsystem is delineated with its required function and essential characteristics listed; an equipment comparison chart follows each subsystem description, with several typical, presently-available equipments listed alphabetically by manufacturer or sponsoring government agency. Each subsystem is rated on the primary characteristics required to perform its necessary function effectively within the overall data correlation system.

The rating system used considers the ability of the subsystem items to meet "ideal-system" requirements. Thus, an "X" rating is the highest possible and indicates that the equipment presently has the required capability. The following key describes the rating system:

X	=	Meets the requirement entirely; no modification is necessary.
G	=	Good fit; only a slight hardware modification is required to provide the capability.
F	=	Fair Fit; a moderate equipment modification will be needed to provide the needed capability.
P	=	Poor fit; here it is judged that extensive rework of the equipment will probably be necessary before the required capability can be attained.

Pilot System selections are indicated in the first nine equipment comparison charts. Section 2 describes in detail the pilot configuration; the arrangement of subsystem components and flow of data are shown in Figure 2-1. Where suitable equipment is available at NASA-Houston, it has been selected for use in the Pilot System; if an appropriate subsystem does not exist at NASA-Houston, or is unavailable to the program, new equipment is called for. Hence, recommendations have also been included to provide for that eventuality.

The selection and rating of equipments is based on technical and cost evaluations, as determined by careful examination of manufacturer's literature, published technical articles, and discussions with technical and sales personnel of the particular companies whose products are listed

in the charts.

Each of the charts uses the following notation scheme:

(1) = Pilot System choice

(2) = Available in NASA-MSC Photo Technology Laboratory

(3) = Available in NASA-MSC Mapping Sciences Photogrammetric Laboratory

(4) = Recommended for Pilot System if primary choice, (1), is not available to the program.

APPENDIX C

CONTENTS

C.1 SENSITOMETER

FUNCTION: Makes precise exposures through a standard stepped density tablet onto undeveloped film.

CHARACTERISTICS:

1. Motorized film transport for rapid, efficient handling.
2. Operation under safelight area illumination
3. Controls for setting exposure time and intensity
4. Built-in color reference strip
5. Allows for insertion of several filters in tandem
6. Handles all film sizes up to and including 9X 9-inch
7. Rapid and easy calibration of exposure lamps
8. Precision lamp stabilization to provide ±5 percent intensity uniformity.

SENSITOMETER COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	Notes
1. Data Corp. Model PS-6809 Sensitometer	G	X	X	X	X	X	X	G	
2. Eastman Kodak Intensity Scale Sensitometer, Type 1B	G	X	X	X	X	G	G	G	(1), (2)
3. Joyce-Gevaert Sensitometer Type 2L	F	G	X	G	G	P	G	F	
4. Technology Inc. Nanosecond Sensitometer	F	X	X	G	G	X	G	G	
5. Tech/Ops Spectral Sensitometer Model 710	F	X	X	G	G	X	X	X	(4)

C.2 DIGITAL DENSITOMETER

FUNCTION: Measures pre-mission and post-mission sensitometric exposures; transfers film calibration data to central computer for guiding later film development.

CHARACTERISTICS:

1. Digital data output with direct computer interface
2. Motorized reels for roll film handling
3. Code Matrix Reader (CMR) to identify each frame to computer storage
4. Accommodates all roll film sizes up to 9 x 9-inch
5. Automatic scanning and film advance
6. Selectable scanning rasters
7. Simultaneous viewing of density values and scanning of film
8. Accepts filters in tandem
9. Self-calibrating by frequent checking of absolute accuracy.

DIGITAL DENSITOMETER COMPARISON CHART

Equipment	Characteristics									
	1	2	3	4	5	6	7	8	9	Notes
1. Itek Recording Densitometer, Model RD-2	X	G	F	G	G	G	X	G	G	
2. Newtek Densitometer, Model 300	X	G	G	G	G	X	X	G	X	
3. Optronics International P-1000 Photoscan	X	G	F	G	G	X	X	G	F	
4. Optronics International S-2000 Stripscan	X	G	F	G	G	X	X	G	F	
5. Photometric Data Systems Automatic Recording Microdensitometer, Model 1010	G	G	G	X	G	X	X	G	G	
6. Tech/Ops (Joyce, Loebl) Automatic Microdensitometer Mark 111CS	G	G	G	X	G	X	X	X	F	(1), (2)
7. Westrex Densitometer Type RA-1100J	G	G	G	F	G	X	X	X	G	(4)

C.3 FILM SCREENING VIEWER

FUNCTION: Rapid visual screening of a copy of the master negatives, frame by frame, with entry into the computer of detailed processing instructions such as: rectify, image enhance, etc.

CHARACTERISTICS:

1. CMR automatically identifies frames to computer
2. Keyboard for entry to computer of detailed frame by frame processing instructions
3. Accommodates roll film sizes from 70 mm to 9 x 9-inch
4. Motorized film transport for ease in viewing and automatic indexing to next frame
5. Variable magnification for small area examination
6. Projection and light table operation
7. Optical image rotation for orienting skewed photographs
8. Continuously variable or stepped control of screen brightness.

FILM SCREENING VIEWER COMPARISON CHART

	Equipment	Characteristics 1	2	3	4	5	6	7	8	Notes
1.	Bausch & Lomb Sloping Screen Viewer	F	G	X	X	X	G	X	X	
2.	Bausch & Lomb Still Picture Viewer	F	G	X	X	X	F	X	X	
3.	Fairchild Viewer Printer, Model F-530	F	G	G	G	G	G	F	X	
4.	Giannini Screening Viewer, Model 706	F	G	X	G	X	X	X	X	
5.	Itek Viewer Printer, Model 30006	F	G	G	G	X	G	F	X	
6.	Northrop Nortronics Model 100 Viewing System	G	G	X	X	X	F	X	X	
7.	Photogrammetry Inc. Multi-Film Inspection Table	P	F	X	X	F	P	P	X	(4)
8.	Richards Multisensor Light Table	F	F	X	G	F	P	P	X	(1), (3)
9.	Traid Corp. Film Viewer/ Reader, Model V/R100	F	G	F	X	X	P	X	X	
10.	Traid Corp. Precision Film Reader Model R-660	F	G	F	X	X	P	X	X	
11.	Zeiss Viewing Desk, Model L-2	P	F	X	G	F	P	P	X	

C.4 COPIER - ENLARGER

FUNCTION: Copies the original negatives onto duplicate or standard format film; provides sufficient copies of all imagery for subsequent processing; allows storage of mission archetype data.

CHARACTERISTICS:

1. Rapid copying to provide the many copies required
2. Input size is 70mm to 9 x 9-inch; output might be standardized at 9 x 9-inch
3. Computer-input control settings determined from film batch reference data of the unexposed film
4. Computer-input control settings from digital densitometer utilized as calibration data
5. Variable magnification, up to 4x required
6. Automatic dodging and automatic exposure control
7. Motorized film transport for rapid frame indexing of new exposures
8. Motorized film transport for rapid frame indexing of input data film
9. Motorized focusing and lamphouse positioning.

COPIER - ENLARGER COMPARISON CHART

	Equipment	Characteristics 1	2	3	4	5	6	7	8	9	Notes
1.	Beseler Diffusion Enlarger	X	G	F	F	X	P	F	F	X	
2.	Calumet Color Enlarger, Model E-100	X	X	F	F	X	P	X	F	X	(4)
3.	Durst 9 x 9-inch Color Enlarger	X	X	F	F	X	P	F	F	X	(1), (2)
4.	Durst L-138S Enlarger	X	G	F	F	X	P	F	F	X	
5.	Log Etronics Electronic Enlarger, Model B-5	X	G	G	G	X	X	G	F	X	

C.5 IMAGE RECONSTITUTION RECORDER

FUNCTION: Reconstitutes imagery from digital tapes.

CHARACTERISTICS:

1. Electronic wedge input for quality control
2. Code Block Encoder (CBE) to identify new reconstructed frames, with a coded array, in subsequent processing
3. Computer-input control settings for time slices of interest and for nominal film exposure
4. Reconstructed hard copy on standardized 9 x 9-inch film
5. High reconstitution rate
6. 64-shade resolution gray scale or greater, with greater than 100:1 dynamic range
7. High resolution, i.e., spot size on the order of 1/4-1 mil
8. High scan accuracy, linearity, repeatability; low geometric distortion
9. Self-calibration capability with test pattern generator
10. Video processing: gamma correction for sensor; contouring.

IMAGE RECONSTITUTION RECORDER COMPARISON CHART

	Equipment	Characteristics 1	2	3	4	5	6	7	8	9	10	Notes
1.	Ampex 100 MHz Electron Beam Recorder (EBR) Syst.	G	G	G	F	X	G	X	X	G	G	
2.	Ampex Laser Beam Recorder	G	G	G	G	X	X	X	X	G	G	
3.	CBS Electron Beam Recorder	G	G	G	G	X	G	X	X	G	G	
4.	Daedalus Tape-Film Conversion Unit	G	G	G	G	X	G	G	X	G	X	
5.	Fairchild FAIRSCAN Image Analyzer Syst.	X	G	G	X	X	X	X	X	G	G	(1)
6.	Goodyear Hi Resolution Laser Recorder	G	G	G	X	X	X	X	X	G	G	
7.	RCA Laser Beam Image Reproducer (LBIR)	G	G	G	X	X	X	G	X	G	G	
8.	Singer - Gen. Precision Media Conversion Film Recorder	X	X	X	F	X	G	G	X	X	X	
9.	Singer-Gen. Precision Video Film Converter	G	G	G	F	X	G	G	X	G	G	

C.6 OPTICAL IMAGE RECTIFIER

FUNCTION: Provides the projective transformation of a tilted photograph into a print that is tilt-free.

CHARACTERISTICS:

1. Motorized reels for rapid throughput of all film sizes up to 9 x 9-inch
2. Quality lens with focal length of at least 5 inches
3. Moderate to high lens speed
4. Easel tilt range of at least ± 10 degrees
5. Capable of 360° swing range
6. Variable magnification
7. Linear displacement in X and Y
8. Corrects displacements in frame photography
9. Corrects displacements in panoramic photography.

OPTICAL IMAGE RECTIFIER COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	9	Notes
1. Bausch & Lomb Autofocusing Rectifier	F	X	G	X	X	X	X	X	P	(4)
2. Fairchild Electro-Optical Rectifier	F	X	F	X	X	X	X	X	X	
3. H. Dell Foster RSS-200 Numerical Rectifying Enlarger	G	X	G	X	G	X	X	X	P	
4. Kargl Rectifier	G	X	G	G	X	X	P	X	P	
5. Zeiss SEG-V Rectifier	F	X	G	X	P	X	X	X	P	(1), (2)

C.7 IMAGE CORRELATOR

FUNCTION: To provide sensor/ground and sensor/sensor imagery correlation with the transfer of known points from one photo to another.

CHARACTERISTICS:

1. Handles a wide variety of formats of different scale and image quality from 70mm to 9 x 9-inch
2. Precision motorized film transport with CMR for both input channels
3. Multiband video correlation circuitry with automatic gain control in each channel
4. Maintains a high reliability of the correlation function
5. Provides a failure routine to cope with correlation failure
6. Good speed & accuracy of error correction
7. Marks known points on ground or sensor-correlated imagery
8. Capable of production rates better than twice that achieved by manual operation.

IMAGE CORRELATOR COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	Notes
1. BAI Corp. Image Correlator	G	G	X	X	G	X	G	X	(1)
2. Bendix Image Correlation System	X	G	X	X	X	X	G	X	
3. General Precision Electronic Correlator	X	G	X	X	G	G	X	G	
4. Itek EC-5 Electronic Image Correlator	X	G	X	X	X	X	G	X	
5. Raytheon Stereo-Image Correlator	X	G	X	X	G	X	G	X	

C.8 ORTHOPHOTOSCOPE

FUNCTION: Produces orthophotographs from a pair of perspective photographs, one orthophoto per frame set.

CHARACTERISTICS:

1. Motorized drive for efficient precision transport of 9 x 9-inch input frames
2. Adjustment for scale, orientation and X-Y translation
3. Fully automatic operation in generating orthophotos
4. CMR for computer identification of each photo set; CBE to associate newly generated orthophotos by exposing a coded array onto them
5. Preparation of color orthophotos
6. Continuous viewing of stereo pairs, either directly or indirectly
7. Total time to prepare an orthophoto from a typical stereo model $\leq$ 2 hours
8. Output negative size up to 9 x 9-inch.

ORTHOPHOTOSCOPE COMPARISON CHART

	Equipment	Characteristics								
		1	2	3	4	5	6	7	8	Notes
1.	Bendix AS-11B1 Automated Analytical Stereoplotter with Orthoprinter	G	X	X	G	G	X	X	X	
2.	Bunker-Ramo Universal Automatic Map Compilation Equipment (UNAMACE)	G	X	X	G	G	X	X	X	
3.	H. Dell Foster RSS 900 Orthophotoscope	F	G	F	G	G	X	G	X	
4.	Itek EC-5 Planimat and GZ 1 System	G	X	X	G	X	X	X	X	
5.	Raytheon B-8 Stereomat	G	X	X	G	G	X	X	X	(1), (3
6.	Raytheon Stereomat A/2000	G	X	X	G	G	X	X	X	
7.	SFOM Orthophotograph 693	F	G	F	G	X	X	G	X	(4)

C.9 FILM SCANNER

FUNCTION: To provide precision scanning, A/D data conversion and magnetic tape recording of input film imagery.

CHARACTERISTICS:

1. Motorized film transport for 9 x 9-inch film
2. CMR for frame identification to computer
3. Capable of scanning transparencies
4. Capable of scanning opaque formats
5. Rapid scan rate
6. Absolute linearity and registration to better than one mil
7. Variable spot size for scanning at different resolutions
8. Dynamic range of at least 64 shades of gray
9. Accepts filters so that registered color separations can be made
10. Provides digital tapes as an output.

FILM SCANNER COMPARISON CHART

Equipment		Characteristics 1	2	3	4	5	6	7	8	9	10	Notes
1.	Aeroflex Pictorial Graphic Digitizer	F	G	X	X	X	F	X	X	F	X	
2.	Fairchild FAIRSCAN Image Analyzer Syst.	F	G	X	X	X	X	X	X	G	X	(1)
3.	IBM 4481 Film Reader/ Recorder	G	G	X	X	X	X	X	X	G	X	
4.	Information International Programmable Film Reader, PFR-3	G	G	X	X	X	F	X	X	F	X	
5.	Link Video Film Converter	G	F	X	G	X	F	X	X	G	X	
6.	Litton Industries Model 1084 Scanning System	F	F	X	X	X	F	G	G	F	X	
7.	McCown Model LDT 8511-1 Laser Translator	F	G	X	X	X	G	X	G	G	X	
8.	Optronics International P-1000 Photoscan	P	F	X	G	X	G	X	X	F	X	
9.	Optronics International S-2000 System Stripscan	P	F	X	G	X	G	X	X	F	X	

C.10 MULTISPECTRAL VIEWER

FUNCTION: Provides the capability to view and evaluate superimposed imagery from several sensors and enables composite false color exposures to be made.

CHARACTERISTICS:

1. Motorized 9 x 9-inch film drive with at least 3 additive color channels
2. Image positioning in X and Y; rotation in the screen plane
3. Precise registration so that identical photos superimpose to within ± 0.005mm across the entire format
4. Film flattening by means of vacuum or glass plates
5. Independent hue, saturation and brightness controls in each channel
6. Screen resolution of at least 15 lines/mm
7. Variable magnification with at least two enlargement values
8. Composite false color exposure capability.

MULTISPECTRAL VIEWER COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	Note
1. Ft. Belvoir USAETL Multiband Additive Color Viewer	G	X	X	X	X	X	X	G	*
2. Giannini Scientific Corp. Additive Color Viewer, Model 6311	G	X	G	X	X	X	X	F	
3. L. I. U. (FSDS) Multi-spectral Film Viewer	P	G	F	X	G	X	G	F	
4. NASA Precision Multi-band Viewer (PMV)	G	X	G	X	X	G	X	F	**
5. Wright-Patterson AF Base (Itek) Additive Color Viewer-Printer	F	X	G	X	X	X	X	F	

* Under development by Aeroneutronic Div. of Philco-Ford Corp.
** Specifications only at this time.

C.11 DIGITAL PLOTTER

FUNCTION: Provides permanent, large format reproduction of computer generated data.

CHARACTERISTICS:

1. Large plotting surface; at least 30 x 30-inch
2. Rapid slewing and plotting speed
3. Good plotting quality, viz. accuracy, repeatability, resolution
4. Interface with computer or magnetic tape
5. Device control by means of digital stepping motors
6. Paper and film used as recording medium
7. Plotting surface can be oriented horizontally or vertically
8. A variety of software available
9. Vacuum paper hold-down adjustable to various sizes of the recording medium.

DIGITAL PLOTTER COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	9
1. Auto-Trol Model 6030	X	G	G	X	X	F	X	X	X
2. Cal. Comp. Model 502	X	G	G	X	X	F	F	X	G
3. Cal. Comp Model 602	X	G	G	X	X	F	F	X	G
4. Computer Industries Digital Drafting System	X	X	X	X	X	F	X	X	X
5. Dresser LGP-2000 Lasergraphic Plotter	X	X	X	X	X	F	F	X	G
6. Electronic Assoc. 430/100 Data-Plotter	X	X	X	X	G	G	F	X	X
7. Geo-Space DP-203	X	X	G	X	G	G	F	X	G
8. Gerber Model 22	X	X	X	X	X	F	X	X	X
9. Gerber Model 75	X	X	X	X	X	F	X	X	X

C.12 COMPUTER OUTPUT RECORDER

FUNCTION: Translates computer-supplied digital data into alphanumerics and graphics and records the results on microfilm and/or paper.

CHARACTERISTICS:

1. Provides alphanumeric and graphic display capability
2. Output recording on 16 mm or 35 mm film
3. Generates hard copy output on white paper in several seconds
4. Viewing screen brilliant enough for viewing in normal room light
5. Superimposes overlays on generated image under program control
6. Character inventory of at least 100 different alphanumeric and special symbols
7. Display head speed in excess of 5×10^4 characters per second
8. Capable of generating plots over better than 3×10^3 by 3×10^3 equal increment, addressable point raster
9. Rapid plotting modes; less than 40 microseconds for any mode, random or sequential.

COMPUTER OUTPUT RECORDER COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	9
1. Cal Comp 1670 Computer Output Microfilm Plotter System	X	X	G	X	X	X	G	X	X
2. Computer Micro-Image Systems CMS-7000 Computer Output Microfilm System	F	X	G	X	X	G	G	X	X
3. Link Film Recorder, APD-5000	X	X	X	X	X	G	X	X	X
4. Stromberg Datagraphics S-C4020 Computer Recorder	X	X	X	X	X	X	X	X	G
5. Stromberg Datagraphics S-D 4060 Data Recording System	X	X	X	F	X	X	X	G	G
6. Kodak KOM-90 Microfilm System	F	G	G	F	X	G	X	X	X

C. 13 OPTICAL ENHANCEMENT EQUIPMENT

FUNCTION: Optically enhances the photographic image without having to scan the entire frame and process it by computer - i.e., optical enhancement as opposed to computer processed enhancement.

CHARACTERISTICS:

1. Motorized film transport control for all film sizes up to 9 x 9-inch
2. Rapid enhancement processing
3. Performs automatic dodging
4. Generates false color imagery
5. Capable of optical spatial filtering
6. Handles a full range of density values from D=o to D=2
7. Dynamic range of at least 32 gray levels
8. Near real time review of enhanced imagery as opposed to lengthy development of individual frames
9. Provides high resolution hard copy.

OPTICAL ENHANCEMENT EQUIPMENT COMPARISON CHART

Equipment	Characteristics 1	2	3	4	5	6	7	8	9
1. Conductron Laser Scan C-120 Photo Enhancement System	G	X	P	P	X	X	F	G	F
2. LogEtronic Electronic Enlarger, Model B-5	G	X	X	P	P	X	X	F	X
3. Morse Contact Printer M-21	F	X	X	P	P	X	X	F	X
4. Spatial Data Systems 702 Datacolor System	G	X	P	X	P	X	G	X	F

C.14 COMPARATOR VIEWER/SPOTTER/LOCATOR

FUNCTION: Locates and records significant geographic points on stereo photographs; provides entry of photo coordinates into computer storage.

CHARACTERISTICS:

1. Simultaneous viewing of stereo pair photographs
2. Independent variable magnification viewing
3. Independent 360° image rotation for both images
4. Rapid coarse scan in both X and Y directions
5. Precise cursor motion over entire usable photographic area for all film sizes up to 9 x 9-inch
6. Output of coordinate data to computer
7. High accuracy determination (several microns) of image reference point coordinates as identified to the computer (photos do not necessarily have to be spotted)
8. Permanent marking of film without damaging adjacent imagery
9. Variety of mark sizes and configurations for film spotting
10. Easy comparison with reference map.

COMPARATOR VIEWER/SPOTTER/LOCATOR EQUIPMENT
COMPARISON CHART

	Equipment	Characteristics 1	2	3	4	5	6	7	8	9	10
1.	Bausch & Lomb Micro-mark Stereo Point Marking Instrument	X	X	X	X	X	F	G	X	X	F
2.	Bausch & Lomb Vari-Scale Stereo Point Marking Inst. (VSPMI)	X	X	X	X	X	X	X	X	X	F
3.	Bausch & Lomb (TPR) Image Point Transfer Instrument	X	X	X	X	X	F	G	X	X	F
4.	Bendix Automatic Comparator	X	X	X	X	X	X	X	F	F	F
5.	Itek Compact, Automatic Registration, Optical Stereoscope (CAROS), Model 5002	X	X	G	X	X	F	G	F	F	G
6.	Jenoptik Jena Stecometer	X	X	X	X	X	X	X	F	F	F
7.	OMI Stereocomparator TA3/P	X	X	F	X	X	X	X	F	F	F
8.	Wild PUG 4 Point Transfer Device	X	X	X	X	X	P	G	X	G	F
9.	Zeiss PSK Precision Stereocomparator	X	G	F	X	X	X	X	G	G	F

C.15 SCAN CONVERTER

FUNCTION: Converts analog/or digital tape imagery into a TV monitor - displayed image; primarily for screening IR and multispectral line scan imagery.

CHARACTERISTICS:

1. Input is analog or digital magnetic tape format
2. High scan converter tube resolution, at least 1600 TV lines per diameter
3. Long storage time, $>$ 2 minutes when read out at standard TV rates
4. Short erase time for single frame
5. Dynamic range of at least 7 shades of gray
6. Signal-to-background shading ratio greater than 7:1
7. Signal-to-disturbance ratio greater than 12:1
8. Manual control for writing, reading & erasing of video information
9. Drives multiple large-screen TV display monitor stations
10. Erasure of selected portions or an entire stored frame.

SCAN CONVERTER COMPARISON CHART

	Equipment	Characteristics 1	2	3	4	5	6	7	8	9	10
1.	Hughes Aircraft Scan Converter System	G	X	G	X	X	X	G	X	G	X
2.	Princeton Electronics Product PEP-400 Video/Graphic Storage Terminal	G	G	G	X	X	X	G	X	G	X
3.	Tektronix 4501 Scan Converter Unit	G	F	X	X	P	G	F	X	G	F